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Programme des pompes de chaleur

Feasibility Study for the Use of Chemical Heat Pumps in Canadian Industry

Acres Consulting Services Limited

March 1984

Canada

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FEASIBILITY STUDY FOR THE USE OF CHEMICAL HEAT PUMPS IN CANADIAN INDUSTRY

A Report prepared for the

Division of Energy
National Research Council of Canada

prepared by
ACRES CONSULTING SERVICES LIMITED
TORONTO, ONTARIO

March 1984

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GLOSSARY OF ABBREVIATION

M	Million (10^6)
Btu	British Thermal Unit
°F	Degree Fahrenheit
°C	Degree Celsius
psia	Pound Per Square Inch Absolute
psig	Pound Per Square Inch Gauge
kW	Kilowatt
kW•h	Kilowatt Hour
lb/h	Pounds Per Hour
Mill	One Thousandth of One Dollar
CHP	Chemical Heat Pump
COP	Coefficient of Performance
h/a	Hours Annually
B	Billion (10^9)
G cal	Gige (10^9) Calories
Kpa	Kilopascals

Note: (1) The units used in this report are imperial units. This is primarily because the basic data used in the investigation was based on imperial units. SI units are shown in parentheses for the principal results of the report.

(2) Unless otherwise indicated, all dollar amounts quoted in this report are in Canadian dollars.

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EXECUTIVE SUMMARY

While various energy cascading equipment and techniques such as heat exchangers, district heating and cogeneration are well developed and often used by industry, a relatively moderate progress has been made in developing a new energy cascading concept by chemical heat pump system in recent years. It is anticipated that chemical heat pump technologies and applications will be slowly undergoing a refining period from a pure research and development stage to commercial installations.

In most energy conservation applications, several alternative methods of heat upgrading or energy utilization improvement can be selected and adopted. Unless a clear anticipated benefit is known, industry may find little incentive to adopt a relatively new technology. In the course of this study, it was discovered that chemical heat pumps can provide unusually effective solutions to certain heat upgrading problems. It is very possible that the process of material drying by air is just such a unique opportunity for chemical heat pump applications. Implementation of this concept in paper manufacturing was reviewed and the continuing development of this new technique is recommended.

Among many chemical heat pump techniques developed today, gas-liquid heat pumps using sulphuric acid or caustic soda fluid as absorbent have been advanced and utilized in pilot projects. Studies further indicated that utilizations of this type of chemical heat pumps in paper manufacturing industry for energy recovery application are beneficial to the industry and technically feasible. Further effort should be directed to implementing demonstration projects in order to refine and further advance this technology.

Based on the result of the economic analysis of a typical demonstration project, this study suggested that chemical heat pump energy recovery projects of this kind are only marginally viable to the industry in today's economic climate. Capital cost assistance of any kind will undoubtedly improve the financial feasibility significantly and likely

become necessary in order to attract demonstration project participants.

The potential for chemical heat pump application in Canadian industry has been reviewed and assessed. It is estimated that approximately 12.8 Gcal (51 MBtu) per year equivalent to about 8.5 M barrels of oil per year, are technically recoverable from rejected waste heat streams by using chemical heat pump systems in Canadian industry as a whole (see Table 8.1).

No attempt was made, in this survey and investigation, to determine the maximum and minimum recoverable energy potential by using chemical heat pump systems. Similarly, no attempt was made to include economic assessments in the survey of potential energy conservation in Canadian industry by chemical heat pump.

SOMMAIRE ADMINISTRATIF

Bien que différents systèmes et techniques de traitement de l'énergie en cascade, par exemple les échangeurs de chaleur, le chauffage collectif et la cogénération, soient bien au point et utilisés couramment par l'industrie, les progrès réalisés dans la mise au point d'un nouveau concept de traitement de l'énergie en cascade au moyen de thermopompes chimiques, au cours des dernières années, ont été relativement intéressants. On prévoit que les techniques et les applications basées sur l'utilisation de thermopompes chimiques connaîtront une période de perfectionnement au cours de laquelle elles passeront lentement du stade de la recherche et développement pure à l'utilisation dans des installations commerciales.

Dans la plupart des applications visant l'économie d'énergie, il est possible de choisir et d'adopter plusiers méthodes de rechange pour produire de la chaleur à température élevée ou pour mieux utiliser l'énergie. Il se peut que l'industrie ne soit pas très intéressée à adopter une technologie relativement nouvelle, à moins d'y avoir un avantage évident. Au cours de la présente étude, on a constaté que les thermopompes chimiques permettent de résoudre de façon très efficace certains problèmes de production de chaleur à température élevée. Il est fort probable que le séchage des matériaux à l'air soit une telle possibilité unique d'application des thermopompes chimiques. On a étudié la possibilité d'application de ce concept à la fabrication du papier et on recommande de continuer la mise au point de cette nouvelle technique.

Parmi les nombreuses techniques basées sur l'utilisation de thermopompes chimiques et mises au point à ce jour, on a perfectionné et utilisé dans des projets pilotes celle des thermopompes gaz-liquide où on utilise une solution d'acide sulfurique ou de soude comme absorbant. Les études ont de plus montré que l'utilisation de ce type de thermopompe

chimique dans l'industrie de la fabrication du papier pour récupérer de l'énergie est avantageuse et techniquement réalisable. On devrait consacrer d'autres efforts à la mise sur pied de projets de démonstration en vue de perfectionner cette technique.

Les résultats de l'analyse de rentabilité d'un projet de démonstration type portent à croire que les projets de récupération d'énergie au moyen de thermopompes chimiques de ce type sont à peine viables pour l'industrie dans la conjoncture économique actuelle. Toute forme d'aide pour financer les immobilisations permettra hors de tout doute d'accroître la faisabilité financière de façon appréciable et deviendra probablement nécessaire pour attirer des participants dans des projets de démonstration.

On a évalué les possibilités d'application des thermopompes chimiques dans l'industrie canadienne. On a estimé qu'environ 12,8 Gcal (51 MBtu), soit environ 8,5 M barils de pétrole, seraient techniquement récupérables annuellement à partir de la chaleur perdue au moyen de systèmes à thermopompes chimiques dans l'ensemble de l'industrie canadienne (voir tableau 8.1).

Dans cette étude, on n'a pas essayé d'évaluer les quantités maximales et minimales d'énergie récupérables par l'utilisation de systèmes à thermopompes chimiques. On n'a pas essayé non plus d'inclure des évaluations de rentabilité dans l'étude des possibilités d'économie d'énergie dans l'industrie canadienne par l'utilisation de thermopompes chimiques.

1 - INTRODUCTION

On November 29, 1983, Supply and Services Canada invited proposals from Consulting Engineering firms for the feasibility study for the use of chemical heat pumps in Canadian industry. In response to the 'Request for Proposal', Acres Consulting Services Limited (Acres) submitted a proposal on December 23, 1983. On January 17, 1984 a telex award was received by Acres. The project was initiated on January 18, 1984 and completed on March 31, 1984 as per the project schedule requirement.

In accordance with the statement of work accompanying the 'Request for Proposal' and the purchase order, this submission addresses the potential heat recovery from industry (particularly paper manufacturing industry) waste heat stream, by means of a chemical heat pump, to produce high quality heat in the form of steam or another high temperature medium. While it is recognized that the most attractive uses of chemical heat pumps remain in situations where simultaneous heating and cooling is utilized, this study covers only the upgrading of heat by chemical heat pump in Canadian industries.

At present, the concept of chemical heat pump applications is still relatively unpopular among industrial energy users. Section 2 of this report examines the current chemical heat pump technology and highlights the basic components of a gas-liquid absorption chemical heat pump system of which similar demonstration projects are being conducted in North America.

Section 3 highlights the potential of chemical heat pump applications for the paper manufacturing industry. A typical gas-liquid absorption chemical heat pump using sulphuric acid or caustic soda is proposed for an energy amplification application at Ontario Paper Co. of Thorold, Ontario. System heat balance calculations are presented to support a demonstration project.

In view of the corrosive and hazardous nature of the chemical to be used, safety and risk considerations are examined in Section 4 together with a review of material application and limitation for the system proposed.

Section 5 develops a typical demonstration project for Ontario Paper Co. utilizing the chemical heat pump system highlighted in Sections 3 and 4. Estimated capital and operating costs and an economic analysis are presented to support the implementation of the demonstration project.

Several project management approaches for the demonstration project are examined in Section 6. An implementation project schedule is also presented to outline the engineering design, construction, commissioning and experimental operation phases of the project works.

By utilizing data published by Lalonde, Girouard, Latendre and Associates Ltd. in a 1981 report entitled "Energy Cascading Potential in Canada Industry", (Reference 21) Sections 7 and 8 review the potential of energy conservation for chemical heat pump applications in Canadian industries.

2 - CHEMICAL HEAT PUMP SYSTEMS

A chemical heat pump utilizes a chemical reaction with a low enthalpy change, so that the reaction may be reversed by a relatively moderate change in temperature or pressure. The condensation of water is not usually thought of as a chemical reaction, but it does meet this requirement. Many chemical heat pumps will utilize reactions of water with other substances. This allows the condensation conditions to be modified to suit requirements.

The following sections discuss some reactions that either use readily available reagents, or have been considered by others for chemical heat pump applications. They are classified according to whether the reaction involves a solid phase, as opposed to two fluid phases. This is a significant practical point, since materials are more difficult to handle for heat transfer purposes in a non-fluid state.

2.1 - Gas-Liquid Absorption Systems

There are two fluids that are outstanding in their thermodynamic properties

(a) Water
(b) Ammonia.

Both these fluids have a low molecular weight (17 and 18 respectively). This determines that the thermal conductivity will be high. They are both polar molecules, which causes them to be chemically active with a great many materials. Their condensation reactions, either alone or with other substances, have a high enthalpy change and yet may be reversed without using extremely high temperatures. Both of these substances are widely used, and their properties are well known.

Ammonia has been associated with refrigeration for many years. At lower temperatures, it has an advantage over water because of it's higher pressure. This allows more compact equipment to be used, which is particularly a concern when mechanical compression is used.

Ammonia may be used in a chemical heat pump by absorbing it into water. The mechanical compressor is replaced by a water circulation loop, which requires only a low power circulating pump. The ammonia-water pair, however, has an unfortunate characteristic in that the vapor pressure of water is high enough to complicate the separation of the ammonia and water in the regenerator. Ammonia is also better suited to refrigeration applications than to the recovery of relatively high grade reject heat, since the high pressure inside the system becomes a disadvantage as the temperature increases.

Water vapor absorption into a solution of a vapor-depressing* salt in water is commercially applied. An air conditioning system has been marketed for many years, using lithium bromide as the vapor depressing salt. This works well for the range of temperatures needed for an air conditioning application. However, the concentration of salt needed to give useful vapor pressure depression at higher temperatures is so high that the salt may crystallize out and plug the equipment. Alternative vapor pressure depressing agents are required at the higher temperatures that are examined in this study.

Sulphuric acid has been promoted recently as a suitable vapor depressing agent. While it certainly avoids the solids deposition problems noted above, it raises a number of material compatibility, safety and environmental problems. These are reviewed in Section 4.

---

* I.e., the solution of this salt in water modifies or depresses the vapor pressure of the liquid, so that at the same temperature the vapor pressure is reduced relative to pure water.

An alternate vapor depressing agent is caustic soda. This is a corrosive material, but it is compatible with mild steel at lower temperatures. For the more extreme conditions that are anticipated in an industrial heat pump, however, more corrosion resistant alloys would be required. Corrosion resistance, safety and environmental problems are reviewed in Section 4.

Design data is required before a chemical heat pump can be designed. Data is readily available for ammonia and lithium bromide. However, it is unusual to apply other absorbing agents for continually operating thermodynamic equipment and data is not available in a suitable format. Sufficient data was found, however, to make preliminary performance analyses for sulphuric acid and caustic soda absorption systems. This data has been re-formatted and included in the appendices.

2.2 - Gas-Solid Absorption Systems

There are two types of gas-solid system that are currently being researched for heat pump applications:

(a) Zeolite-water
(b) Metal-hydride

The zeolite-water system is attractive in that it may use a low-cost natural zeolite as the absorbing agent, or alternatively it may use one of the synthetic zeolites. These are already applied on quite a large scale in industry as drying agents, catalysts, for selective gas absorption or water purification by ion exchange.

Metal-hydride systems use relatively high cost materials. They will probably find application in more specialized areas, such as hydrogen storage or hydrogen isotope removal from nuclear reactors, before they are used for energy conservation applications in industry.

While zeolite systems could doubtless find cost-effective applications in industry, this report has chosen to concentrate on the gas-liquid systems. This avoids the potential design problems in handling the solid phase.

2.3 - Gas-Liquid Heat Pump Design Principles

Figure 2.1 shows a diagram of a gas-liquid sulphuric acid heat pump system. The same configuration would apply for either a sulphuric acid or caustic soda based system. It would not be suitable, however, for use with ammonia because of the difficulty in separating the ammonia/water mixture and the high pressures that would be obtained at the temperatures of interest. The principal components are as follows

(a) Absorber

This contacts the regenerated liquid with water vapor. In an open cycle, the steam would be fed directly to this vessel, as shown in Figure 2.1. The absorber could use a tray layout as shown, or it could be a packed column, or a spray tower. A circulating pump is shown, and would be sized to match the height of the absorber and to provide energy for spray atomization if this is used in the design.

(b) Regenerator

Heat energy is supplied to this vessel to regenerate the absorbent. Clean steam is driven off. This steam is in a superheated condition because the vapor pressure of the absorbent does not match the saturation vapor pressure of the steam. For either sulphuric acid or caustic soda, very little direct vaporization of the absorbent is expected. Vapor pressure data is given for sulphuric acid in the appendix 1. Caustic soda will have an even lower vapor pressure. In both cases, however, there is the possibility of particle entrainment. Experience in the power

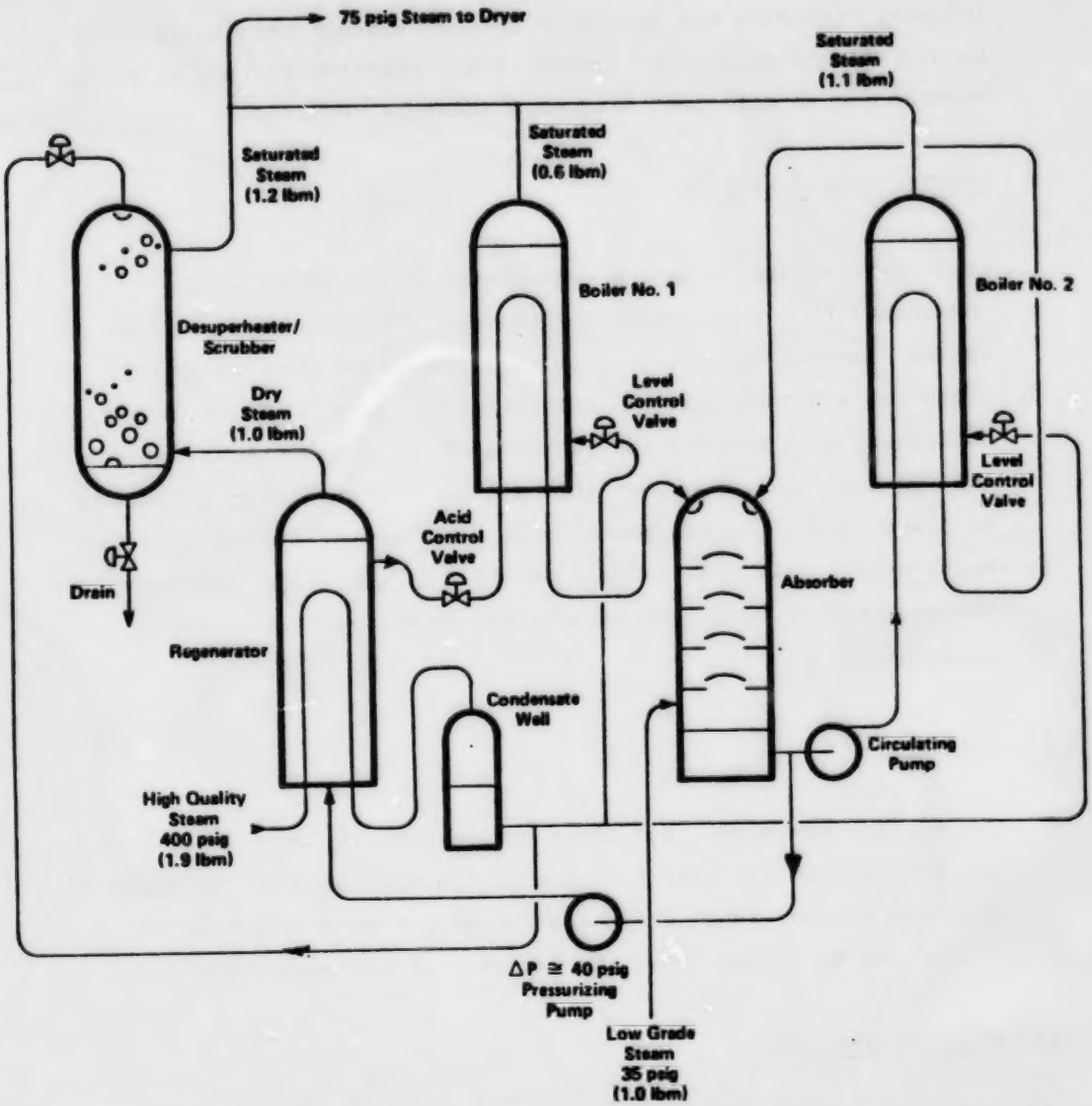

Figure 2.1

SULFURIC ACID HEAT PUMP FLOW DIAGRAM

Note: lbm = lb mass

industry with flue gas desulphurization suggests that entrainment is significant with spray towers (i.e., relative to tray or packed towers) and an efficient mist eliminator is required.

(c) Scrubber/Desuperheater

Steam carried over from the regenerator is contacted with condensate from the regenerator heater. The condensate carries excess heat for the pressure in this vessel and some steam will flash off and contribute to the main steam flow. The remaining condensate will contact the superheated steam and a small portion will be used to desuperheat this steam. The remaining condensate will wash the steam and vessel packing to reduce absorbent carry-over. This vessel could be sized to contain a boil-over from the regenerator, which is conceivable in the event of control malfunction.

(d) Boilers

Two boilers are shown, but these could share the same outer shell. The regenerated fluid is hotter than the absorbent in the absorber, and some economy in heat exchanger area can be obtained if the fluids are not mixed until the excess heat has been removed.

(e) Pressurizing pump

This is the largest work input to the system. The work input is much smaller than the work input to a conventional heat pump, and an electrical coefficient of performance of 50 or so can be expected.

(f) Controls

The primary controlled variable is the mass flow of the absorbent. This is adjusted to satisfy temperature and level criteria in the

absorber and regenerators. This flow rate must be a modulated variable. Secondary controls must be provided for condensate flow to the boiler(s) to maintain boiler level, and to regulate condensate flow to the scrubber/desuperheater in response to level in the condensate well.

3 - OPPORTUNITIES FOR A CHEMICAL HEAT PUMP IN PAPER MANUFACTURING

3.1 - Overview of Paper Manufacturing

Paper manufacturing is an energy intensive process, and is carried out on a large scale in Canada. The lower cost grades of paper are produced in the greatest quantity and are intended for use in, for example, newspapers. These lower cost grades are made from a pulp produced primarily from woodchips, with only partial removal of the non-cellulose portion of the wood. Many paper manufacturing plants have recently upgraded their pulp production process. The traditional method for producing pulp was based on a stone grinding operation with an excess of water to carry away surplus heat. The resulting mechanical pulp may be blended with a chemically treated pulp produced from wood chips in a batch heating process. The modern trend is towards continuous pulping methods, so that a steady flow of waste heat is available at a useful temperature. The process is known as thermo mechanical pulp refining, or TMP in abbreviated form. The large flow of waste heat is of interest, since it can greatly improve the economics of a mill operation if it can be effectively utilized (Reference 3).

The pulp must be formed into a mat of fibres and then dried. This is a particularly critical and energy intensive stage of manufacture. The rolls carrying the fragile mat of wet fibres must be carefully controlled to avoid breakage. Heat must be applied so that the paper dries at a sufficiently fast rate to maintain production, without damaging the mat of fibres. Steam is used as the heat transport medium, and the temperature is controlled by adjusting the steam pressure inside the drying rolls. Steam is also used to heat air which is supplied to pockets formed by the paper as it loops between rolls. Some of the drying energy is reclaimed to preheat drying air brought in to replace the moisture laden air, which must exhausted from the building. The energy consumed in paper drying, and the affect of process changes, were highlighted in the referenced literatures (see References 4,5,6,7,8). A

modern installation will enclose the drying section of the paper machine to control the drying air, so that less air carrying more moisture is rejected from the building. Much of the heat will be reclaimed for water heating before the moisture laden air is discharged from the building.

With the recent introduction of the new TMP pulping technology, it is considered feasible to utilize the waste heat from the pulping process to dry the paper. It has even been proposed that all the paper drying energy may be supplied from the TMP refiner (Reference 9).

3.2 - Ontario Paper Company

The Ontario Paper Company at Thorold, Ontario have recently expanded and modernized their operations. They now obtain pulp fibres from four sources

(a) Thermomechanical pulping, as described in Section 3.1. Softwood chips are used as the raw material.

(b) Chemimechanical pulping, using a similar refining stage to that used in the TMP process, but with a chemical pretreatment. Hardwood (poplar) chips are used as the raw material.

(c) Sulphite pulping is still carried on, and produces lignin-free fibre for paper making as well as liquor for by-product chemicals.

(d) De-inked pulp from salvaged newspapers.

These processes are illustrated in Figure 3.1.

The Ontario Paper Company was originally approached with the idea of using a chemical heat pump to reclaim reject heat from the drying train. The proposal is illustrated in Figure 3.2. The chemical heat pump proposed is an open cycle system, and minimizes heat exchanger area by

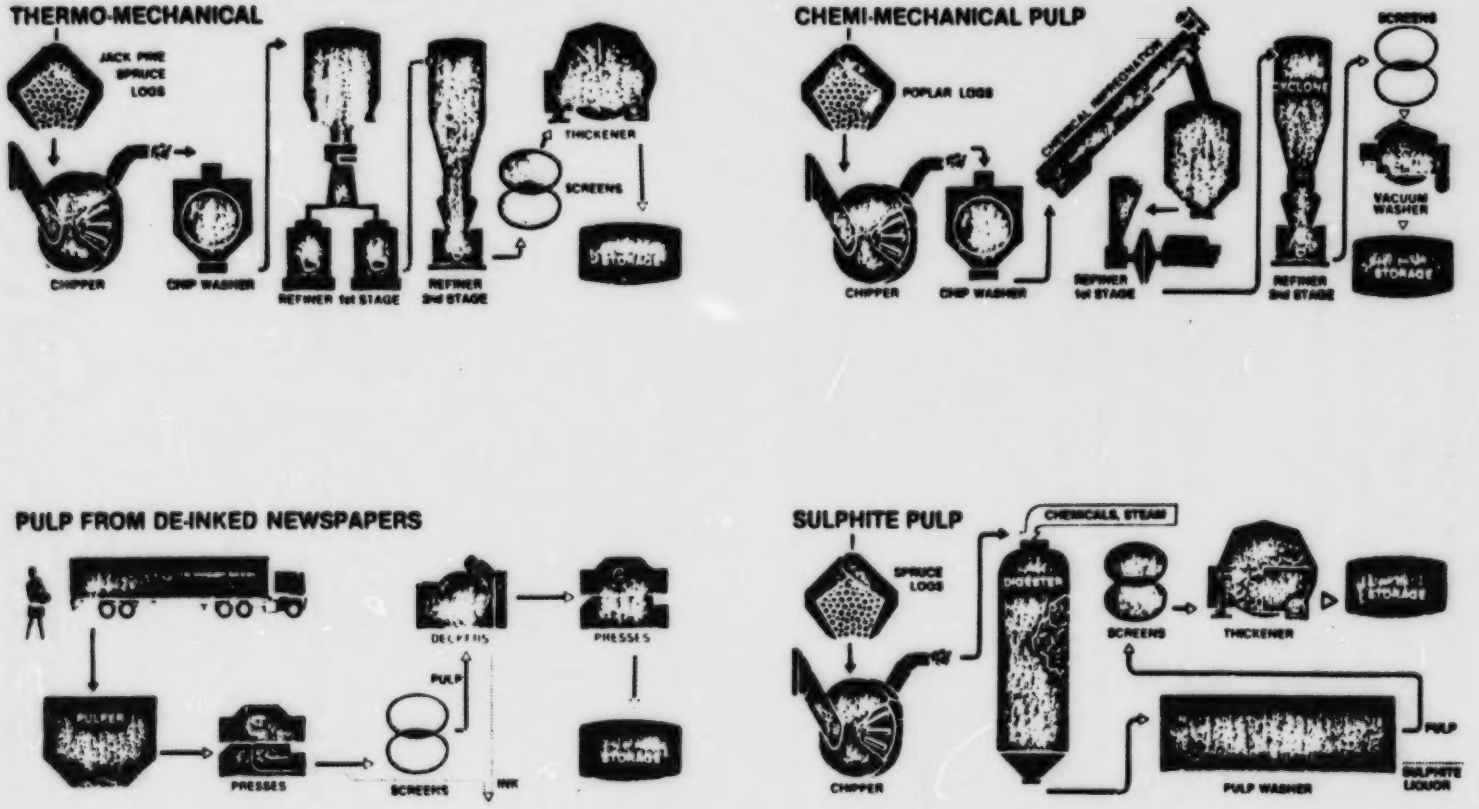

Figure 3.1

PULP MANUFACTURING AT THE THOROLD MILL, ONTARIO PAPER COMPANY

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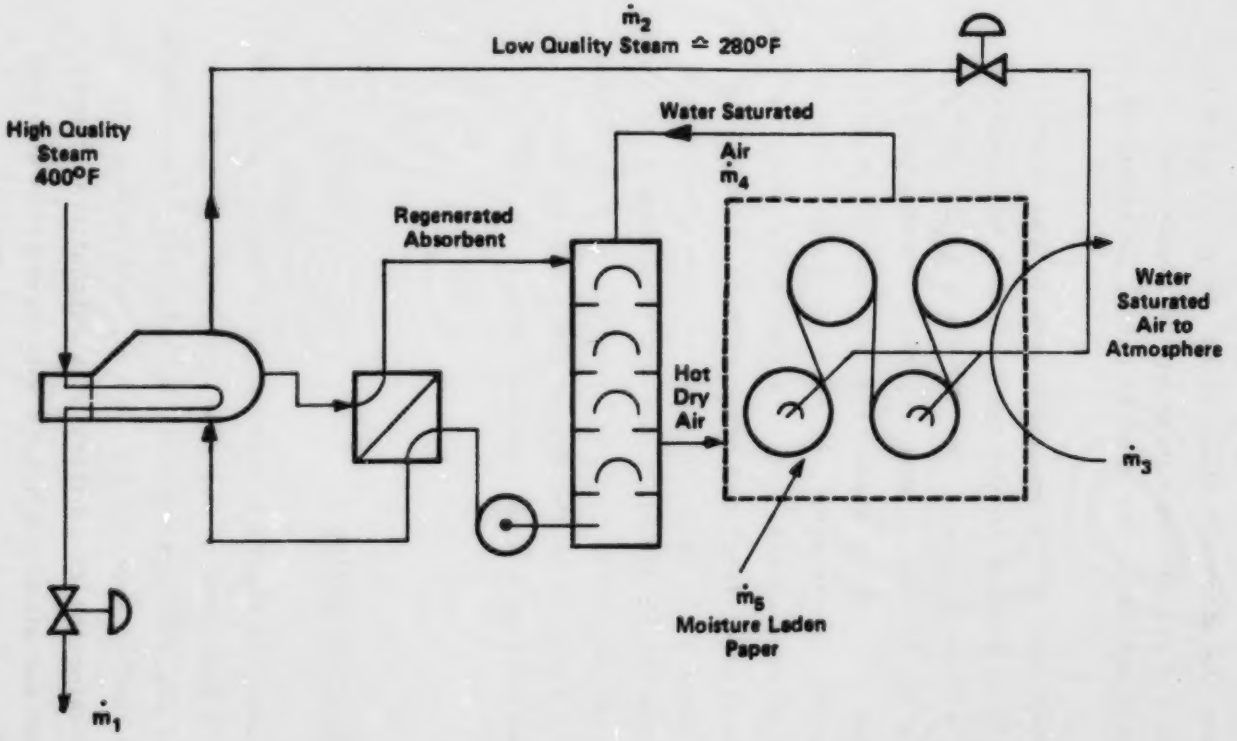

NOTES: 1) Cascade effect as illustrated will approximately double the effectiveness of the high quality steam.

2) Mass flows m refer to moisture only.

$m_5 = 1$

$m_1 \triangleq m_2 \triangleq m_3 \triangleq m_4 = 0.5$

Figure 3.2

CHEMICAL HEAT PUMP
PAPER DRYING

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contacting moist air and the absorbent directly at the point where heat is generated. The heat and mass balance data on the figure are approximate only and have not been confirmed by detail calculations.

The Ontario Paper Company were in the process of evaluating an energy conservation proposal to be applied to the TMP line that had recently been commissioned at the Thorold plant. The TMP steam is currently exhausted directly from the building. However, the TMP refiners are fitted with ducting that could carry steam rejected from the process at moderately high pressures. It was estimated that the steam could be obtained at a pressure of approximately 50 psig (345 Kpa). After a heat exchanger operation (to prevent fibre and organics from reaching the drying system), clean steam at 37 psig (255 Kpa) could be available. The proposal under evaluation by Ontario Paper was to upgrade this clean steam using thermocompression (steam jet compressors), so that 75 psig (517 Kpa) steam could be supplied to the drying train. Steam at 400 psig (2,758 Kpa) was available from the plant boiler for this purpose.

3.3 - TMP Steam Upgrading Application

It was decided to evaluate the use of a chemical heat pump in place of the thermocompressor. A heat balance was done using sulphuric acid as the absorbent (Appendix 3), and caustic soda (Appendix 4). The application was discussed with Rocket Research in Redmond, Washington. This company has been researching the feasibility of a sulphuric acid heat pump. They advised that the steam conditions were manageable and gave an informal opinion that a coefficient of performance (COP) in the heating mode of 1.5 was feasible. This checks well with the heat balances given in Appendices 3 and 4. The equipment configuration to give this performance is as shown in Figure 2.1. This data can be used to evaluate the affect of a heat exchanger between the stream of weak and strong absorbents. For a heat exchanger effectiveness of .8 (i.e., 80 percent of the sensible heat in the flow of strong absorbent is transferred to the weak absorbent solution), then the COP is improved

slightly to between 1.5 and 1.6. These configurations are not based on Rocket Research designs, which were not available in time for this study. Principal mass flows are

400 psig (2,758 Kpa) steam - 1.9 mass units
37 psig (255 Kpa) steam - 1 mass unit.

Drying steam

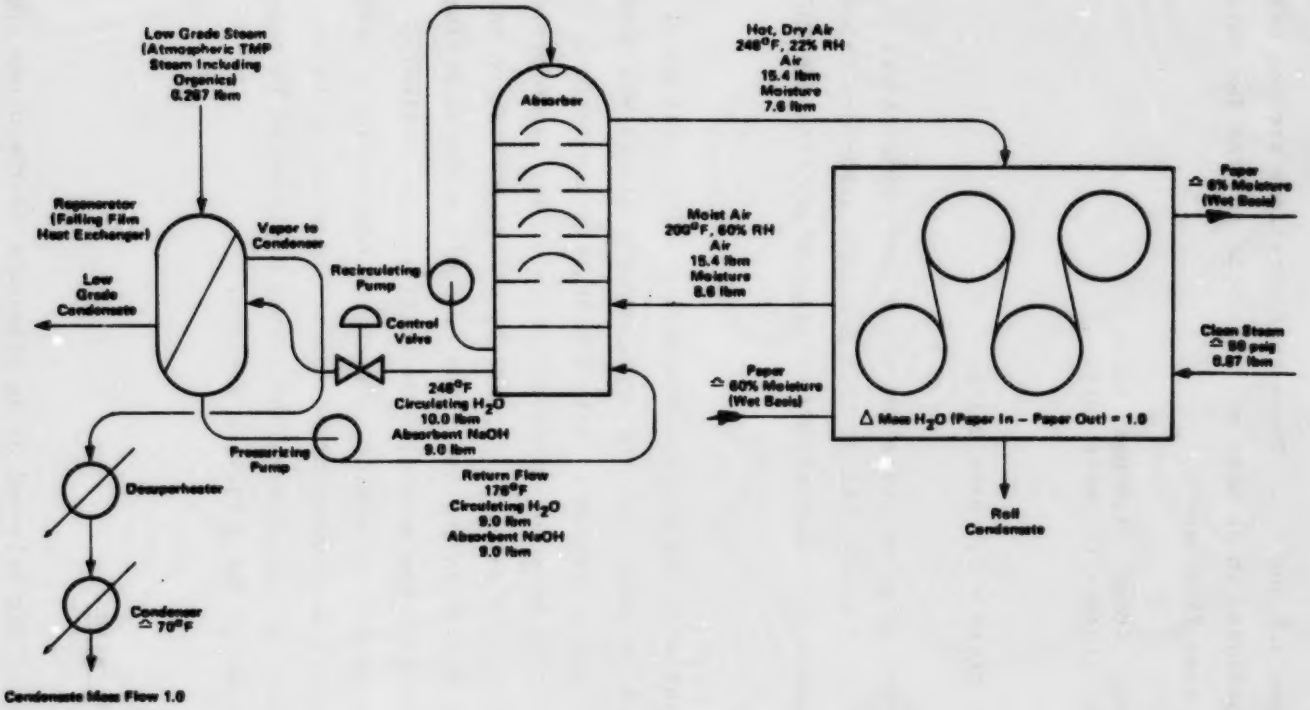
75 psig (517 Kpa) steam - 2.9 mass units.

This can be compared to steam upgrading using thermocompressors (reference 3), where 2 mass units of high pressure steam are found to be required to upgrade 1 mass unit of low pressure steam from the TMP refiners.

This analysis quantifies the performance of a chemical heat pump. However, it should be noted that the performance analysis was done with limited data that was extrapolated into a high pressure region. The authors of this report have not witnessed tests of any bench scale or prototype equipment. No detailed reports by others working on this kind of equipment have been reviewed. The economic analysis performed in later sections examines the economic feasibility. It is likely, however, that the relatively simple, proven jet compression alternative would be a more practical course of action if the steam is to be upgraded. For this reason, chemical heat pump application to paper drying is considered in the following section.

3.4 - Drying Application

A drying application was selected as an alternate to the steam upgrading example. A performance analysis is contained in Appendix 5, and the configuration is illustrated in Figure 3.3. It assumes a situation where steam suitable for the drying rolls (i.e., clean steam at 50 to 75 psig (or 345 Kpa to 517 Kpa)) is at a premium. An adequate supply of steam is available at close to atmospheric pressure. This could be



NOTE: Mass Flow in lbm

Figure 3.3

CHEMICAL HEAT PUMP FOR
HIGH EFFICIENCY PAPER DRYING

waste steam from an atmospheric pressure TMP refiner. It is intended that the losses associated with the discharge to atmosphere of warm air conveying the moisture removed from the paper should be eliminated. These losses can be very substantial (Reference 15). However,the paper industry can usually utilize quite a high proportion of this waste heat for warming wash water so that drying losses are less than they might otherwise be (Reference 7).

The heat balance was repeated with increasing air circulation, until the results displayed were obtained. A useful portion of the latent heat released as the water was absorbed into the caustic soda then became available to reduce the steam supply to the drying rolls. This is effectively cascading the drying energy, which is often done in liquid concentration or purification (desalination, for example), but is more difficult to achieve in a solids drying application. The air circulation could have been increased beyond that shown in the heat balance, so that the high quality steam demand would be reduced even more. However, the air handling equipment (ductwork, fan and absorption tower) would have increased in size and cost in proportion to the increase in air mass flow. No attempt was made to investigate the economics of these design options. The analysis was not complete, since air moving power was not examined.

An alternate variation on the drying example could investigate the use of latent heat from the moist drying air to regenerate the absorbent. This would reduce the demand for the lower pressure regeneration steam, and may be more suitable when all the TMP steam can be obtained in pressurized form. In a paper plant such as the Ontario Paper mill at Thorold, some of the fibre is obtained from sources other than the TMP process. In such a case, the TMP steam is not likely to be sufficient for all paper drying needs, even if the energy is cascaded using a chemical heat pump. In such a case, waste warm water streams (i.e., condensate, wash water) could be used for absorber regeneration.

4 - FEASIBILITY BOUNDARIES OF A GAS-LIQUID HEAT PUMP

This section discusses some of the factors that should be considered in determining the feasibility of a chemical heat pump proposal. The use of two absorbing materials, sulphuric acid and caustic soda, is examined.

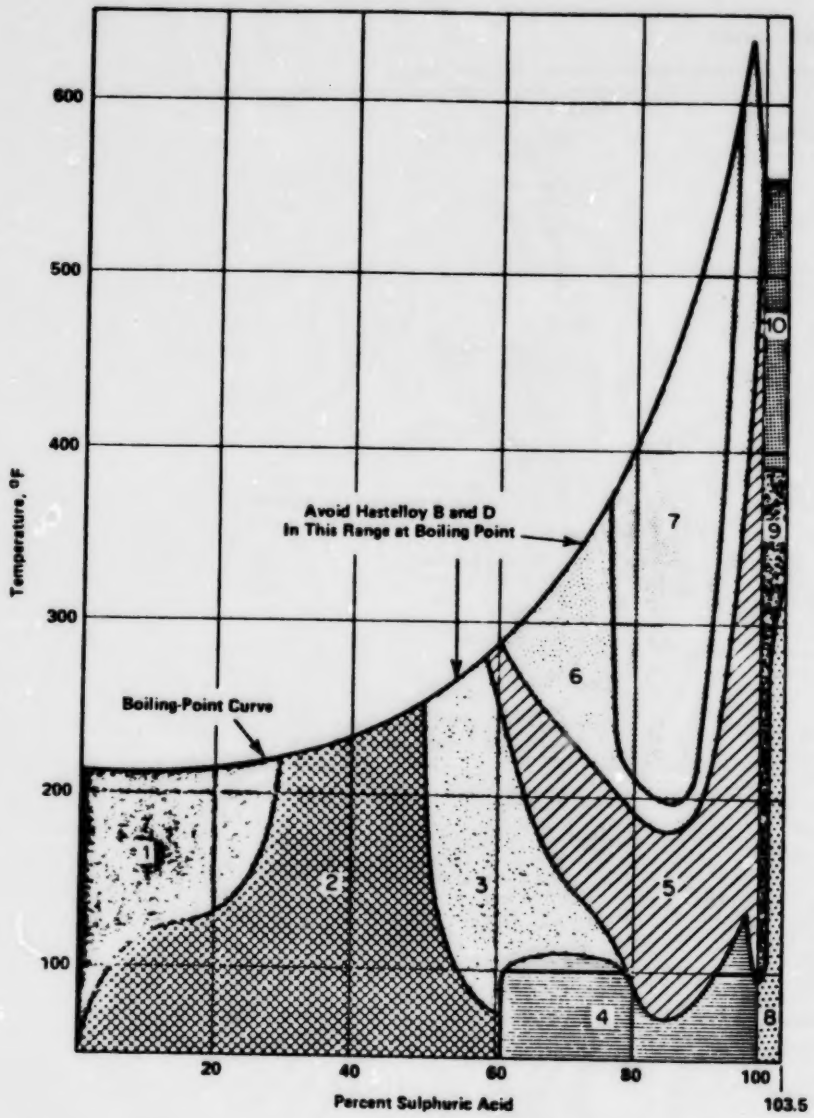
4.1 - Materials Limitations

Both caustic soda and sulphuric acid are strong reagents and care must be used in selecting materials of construction. The combination of reagent concentration and temperature may call for either high alloy metals or nonmetallic materials.

4.1.1 - Sulphuric Acid

Sulphuric acid is used extensively in industry and considerable experience has been gained with its corrosion reaction rates with materials of construction. Figure 4.1 gives a summary of this experience. Reference 17 indicates that glass-lined steel will perform well with concentrated sulphuric acid to 450°F, and teflon can be used up to 500°F. Stainless steel (i.e., Durimet 20 or 20 alloy, 24 percent Ni and 20 percent Cr) is used extensively for sulphuric acid, for all concentrations and temperatures up to 150°F. High silicon iron (i.e., Duriron, 13 to 16 percent silicon) is useable over a wide range of temperatures and concentrations. Materials with good corrosion resistance but improved mechanical properties are available (i.e., Hastelloy, see Figure 4-1 for limitations).

Rocket Research described the materials used in their design of sulphuric acid heat pump. They intend to use glass lined steel vessels and pyrex glass heat exchanger tubing. High silicon iron (Duriron) can be used for heat exchanger tubesheets, and teflon seals to seal the tube to



NOTE:

Corrosion resistance of materials to sulphuric acid. Criterion – loss of material 0.020 in./year or less. (G.A. Nelson, Shell Development Co.)

Figure 4.1

MATERIALS LIMITATION
SULPHURIC ACID

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Code for Sulfuric Acid Chart

Materials in shaded zones having reported corrosion rate less than 20 mpy

10% aluminum bronze (air free) Illium G Glass Hastelloy B and D Durimet 20 Worthite Lead Copper (air free) Monel (air free) Haveg 43 Rubber (up to 170°F)	***Zone 1*** Impervious graphite Tantalum Gold Platinum Silver Zirconium Nionel Tungsten Molybdenum Type 316 stainless (up to 10% aerated)
Glass Silicon iron Hastelloy B and D Durimet 20 (up to 150°F) Worthite (up to 150°F) Lead Copper (air free) Monel (air free) Haveg 43 Rubber (up to 170°F) 10% aluminum bronze (air free)	***Zone 2*** Ni-Resist (up to 20% at 75°F) Impervious graphite Tantalum Gold Platinum Silver Zirconium Nionel Tungsten Molybdenum Type 316 stainless (up to 25% at 75°F) aerated
Glass Silicon iron Hastelloy B and D Durimet 20 (up to 150°F) Worthite (up to 150°F) Lead Monel (air free)	***Zone 3*** Impervious graphite Tantalum Gold Platinum Zirconium Molybdenum
Steel Glass Silicon iron Hastelloy B and D Lead (up to 96% H_2SO_4) Durimet 20 Worthite	***Zone 4*** Ni-Resist Type 316 stainless (above 80%) Impervious graphite (up to 96% H_2SO_4) Tantalum Gold Platinum Zirconium
Glass Silicon iron Hastelloy B and D Durimet 20 (up to 150°F) Worthite (up to 150°F)	***Zone 5*** Lead (up to 175°F and 96% H_2SO_4) Impervious graphite (up to 175°F and 96% H_2SO_4) Tantalum Gold Platinum
Glass Silicon iron Hastelloy B and D (20–50 mpy)	***Zone 6*** Tantalum Gold Platinum
Glass Silicon iron Tantalum	***Zone 7*** Gold Platinum
Glass Steel 18 Cr-8 Ni Durimet 20	***Zone 8*** Worthite Hastelloy C Gold Platinum
Glass 18 Cr-8 Ni Durimet 20	***Zone 9*** Worthite Gold Platinum
Glass Gold	***Zone 10*** Platinum

Figure 4.1 (b)

MATERIALS LIMITATIONS
SULPHURIC ACID

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tubesheet joint. Duriron can be used for the pump impellors. All these material selections are consistent with typical industrial practice when handling sulphuric acid. They would appear to be adequate for the temperatures proposed in Section 3 and analyzed in Appendix 3.

4.1.2 - Caustic Soda

Caustic soda can be handled at low temperatures using ordinary steel. However, at higher temperatures, caustic embrittlement is a concern (Figure 4.2). Austenitic (nickel bearing) stainless can be used to minimize this effect. Other measures would be to choose a higher nickel content alloy (i.e., use Inconel in preference to 304 alloy), or to reduce the stress level. A caustic soda based chemical heat pump would be built using metallic materials of construction and could make extensive use of welded joints to minimize the possibility of leakage.

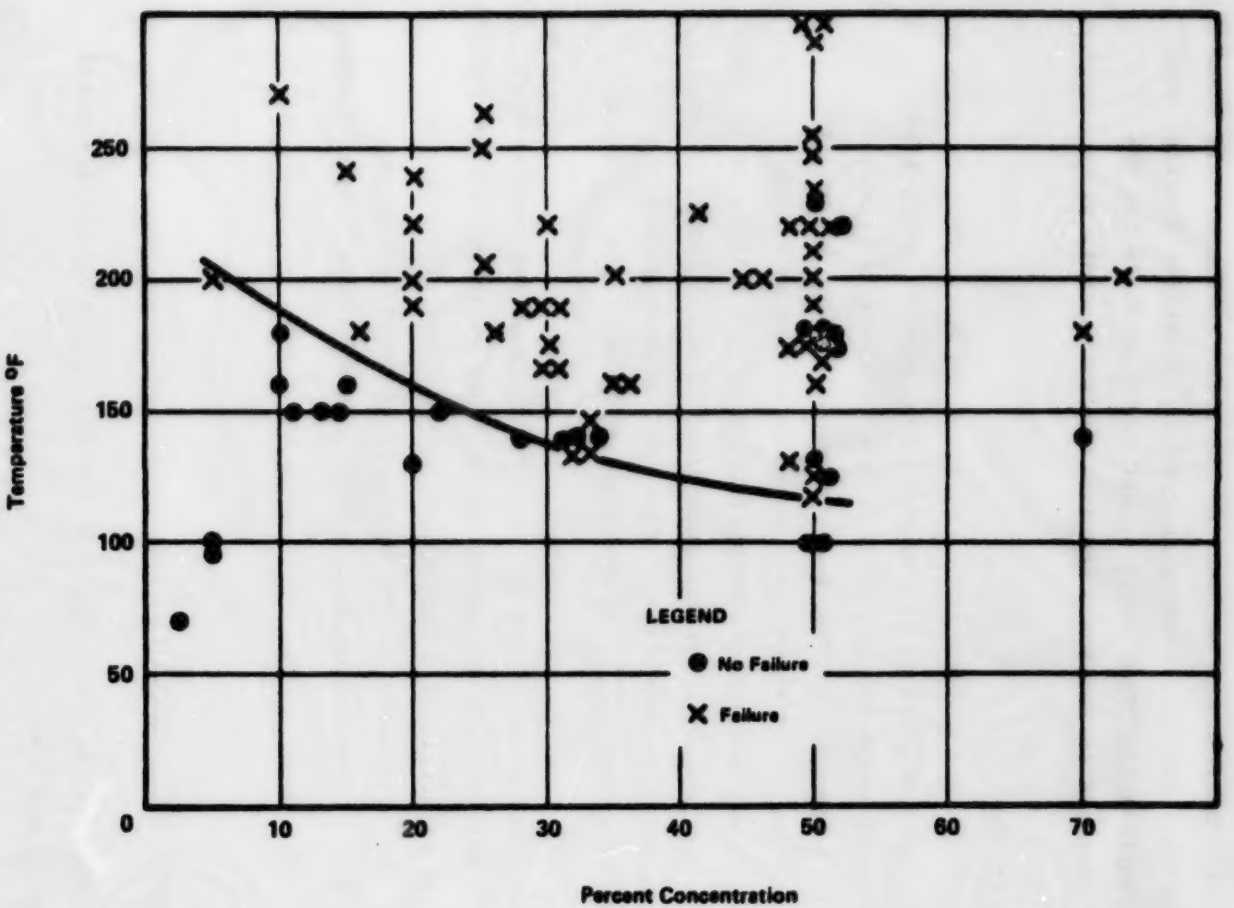
A caustic soda absorption heat pump could be designed for temperatures up to 500°F. However, a lower design temperature would permit the use of less costly materials of construction. Regardless of the design temperature, the resistance of the materials of construction to caustic embrittlement or stress corrosion cracking should be carefully reviewed (Reference 16).

4.2 - Competing Technologies

The options that can be considered for thermal upgrading are discussed in Reference 22 and are

(a) thermocompressor
(b) mechanical heat pump
(c) absorption or chemical heat pump.

Section 3 has already compared the thermocompressor and absorption heat pump. The absorption heat pump did not have a significant advantage over the thermocompressor, probably because the thermocompressor is well



NOTE:

Effects of temperature and concentration on the cracking of as-welded carbon steel in sodium hydroxide (H.W. Schmidt, P.J. Gegner, E.G. Wyche, Corrosion, 1951)

Figure 4.2

MATERIALS LIMITATIONS
CAUSTIC SODA

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suited to a low temperature rise application where the low thermodynamic efficiency is not a major drawback. For a drying application, mechanical refrigeration (Reference 15) can be compared to an absorption cycle. It is likely that the absorption cycle will be attractive, particularly if there is a suitable supply of waste heat available. The economics of a mechanical refrigeration installation may suffer from the large amount of heat that must be transferred through heat exchangers. An absorption unit, by contrast, can remove moisture from an air stream without removing the sensible heat contained in that air. The latent heat released from the moisture is transferred directly back to the air stream and is available to evaporate more moisture.

Mechanical heat pumping can be achieved by direct vapor recompression. This process has a good thermodynamic efficiency. However, the mechanical equipment (i.e., turbocompressor) is complex and will only be justifiable in larger installations. Small positive displacement compressors are likely to require frequent maintenance and will not have good efficiency when compressing steam at low pressures. A turbo-compressor could be driven by an electric motor drive, or it could be driven by a steam or gas turbine driver. The turbine driver will run at a high speed that is more likely to match the high speeds that are required for an economical turbocompressor.

4.3 - Safety and Risk Considerations

Any of the chemical heat pump designs discussed in Section 3 have an obvious potential for hazard to life and property. Since the equipment is a new concept, some kind of hazard assessment should be a part of the design process. A methodology is available for this (Reference 23).

While the absorbents are strong reagents, they can be neutralized readily and the resultant products are common substances that pose little threat to the environment.

5 - DEMONSTRATION PROJECT ECONOMIC ANALYSIS

Chemical heat pumps represent a relative new technology base for energy conservation applications. While the technology development appears to be moderate, there is no commercial installations reported yet in North America. A 0.38-G cal/h (150 000 Btu/h) CHP demonstration project was implemented by an American company, Rocket Research Company of Redmond, Washington. It was also reported by the same company that a 0.5-G cal/h (2 M Btu/h) and a 3.8-G cal/h (15 M Btu/h) pilot projects are being planned (Reference 20).

Sections 3 and 4 of this report examined the feasibilities of CHP application in paper manufacturing industry, particularly on the TMP steam upgrading and the paper drying applications in Ontario Paper Co. at Thorold, Ontario. It is suggested that these CHP applications are technically feasible and pilot projects should be implemented in order to further development the CHP application technology.

During the course of this study, Ontario Paper Co. not only expressed their interests on the CHP application but also provided generous supports and assistances to the author. The possibility of holding a demonstration project was proposed to, and is being studied by, Ontario Paper Co.

In order to illustrate the financial commitments required from the host industry and sponsors and the methodologies of implementing capital projects for this type of application, a typical demonstration project scheme is presented below.

5.1 - Demonstration Project CHP Unit

The study host industry, Ontario Paper Co. in Thorold, Ontario, has indicated their interest in the possibility of chemical heat pump applications to recover waste energy in an amount equivalent to

90 000 lb/h of clean steam at 24/Kpa or 35 psig pressure. (See Appendix 6, Ontario Paper's letter of February 17, 1984.) This will require a CHP unit of (26.7 G cal/h) 106 M Btu/h output capacity. While the current sulphuric acid chemical heat pump design information is limited to a maximum unit size of about (3.86 G cal/h) 15 M Btu/h output for energy amplification application, (Reference 20) the potential equipment vendors suggested that

(a) the CHP units larger than (3.8 Kpa/h) 15 M Btu/h output will not likely be developed in the next few years due to the slow market demand

(b) multiple units can be considered for applications requiring higher output capacity.

For the purpose of this study, it was assumed that the demonstration project is to be implemented on the basis of a single sulphuric acid (or caustic soda) CHP unit with a maximum output capacity of (3.86 G cal/h) 15 M Btu/h. It was further assumed that the economic life of the CHP unit is to be a chemical industry average of 15 years.

Based on an anticipated coefficient of performance of 1.50 for the CHP unit, the net energy recovered by the (3.8 G cal/h) 15-M Btu/h CHP unit will be (1.26 G cal/h) 5.0 M Btu/h. Assuming an overall boiler efficiency of 71 percent (average efficiency for utility boiler) and a 10 percent mechanical and piping loss, this amount of recovered energy will be equivalent to about (2.07 G cal/h) 8.2 M Btu/h boiler fuel saving.

5.1.1 - Capital Cost Estimate

(a)	Equipment and Material	Equipment and Material Cost	Erection Cost	Total Cost
	Chemical Heat Pump Unit	$550,000	$40,000	$ 590,000
	Piping	14,000	20,000	34,000
	Misc. Mech. Items	20,000	20,000	40,000
	Misc. Elec. Items	80,000	30,000	110,000
	Sulphuric Acid/ Caustic Soda Neutralize Equipment	10,000	5,000	15,000
	CHP Building Fdn. & Misc. Civil	Supply & Erect	40,000	40,000
(b)	Total Direct Cost			829,000
(c)	Interest During Construction			65,900
(d)	Engineering and Design			170,000
(e)	Construction Management			70,000
(f)	Commissioning			30,000
(g)	Total Indirect Cost			335,900
(h)	Contingency			93,200
(i)	Total Capital Cost			$1,258,100

The capital cost estimates are based on

- engineering and construction period to be 24 months. (See Figure 6.1)

- interest during construction to be equal to the real cost of borrowing--6 percent

- eight percent contingency of the total direct and indirect costs

- the normal plant operations will not be interrupted by the installation of the CHP addition.

In the absence of a complete detail design, the capital cost shown above should be regarded as an 'order of magnitude' estimate.

5.1.2 - Operating Cost Estimate

Energy Cost	$42,300/a
Operating and Maintenance Labor and Material	12,000/a
Total	$54,300/a

Energy cost is based on

- the CHP electrical COP to be 25 and a total of 235 kW of motors is required for all circulating pumps

- the annual operating capacity factor to be 0.85 and the CHP unit to be operated 7,500 h/a

- electricity cost to be 30 mill/kW·h for industrial users.

The operating and maintenance cost is based on

- only one part-time operator is required to operate the CHP. It is assumed that this operator also operates other systems in the plant and will only spend about 600 h/a to operate the CHP unit

- maintenance, labor and material costs are assumed to be an average of $3,000/a.

5 2 - Hazard Control and Environmental Protection Costs

Due to the hazardous and corrosive nature of the caustic soda or sulphuric acid, potential sulphuric acid CHP users undoubtedly emphasize the safety and protection aspect of the system. The safety and risk considerations for the demonstration project are outlined in Section 4.3 of this report and will be further assessed and evaluated in the future detail engineering phase of the project.

It is vital that the CHP equipment must be designed to achieve three main objectives in relation to the safe use of the sulphuric acid solution.

(1) Minimize corrosion by using suitable corrosive-resistant material.

(2) Minimize the possibility of spillage by using a close chemical cycle.

(3) Provide acid leak detection device and system.

The costs associated with these measures are included in the CHP equipment costs shown in Section 5.1.1.

In addition to the CHP equipment design considerations, several proposed safety and protection measures are listed below.

(1) The CHP package unit is to be housed in a separate building in order to isolate chemical handling and operation.

(2) The CHP building is to be designed with concrete curb around to contain acid spill in case of leaks.

(3) Chemical neutralizing system is to be provided.

(4) Maintain adequate ventilation in the CHP building year-round.

The total capital cost of these safety measures is estimated to be $45,000 ($55,000 as shown in Section 5.1.1 less $10,000 foundation cost).

The CHP unit foundation cost is excluded since it cannot be considered as a safety measure.

5.3 - Unit Capital Cost

The capital cost per energy unit (total capital cost/total unit capacity) can be expressed in three different forms as shown below based on the definition of 'total unit capacity'.

1. Unit installed capacity - $1,258,100/15 M Btu/h or $286/kW
2. Net energy recover capacity - $1,258,100/5 M Btu/h or $858/kW
3. Equivalent fuel energy capacity - $1,258,100/8.2 M Btu/h or $523/kW

The figure of $858/kW should be used for unit capital cost comparison with other type of energy installation since this represents the net energy recovered by the CHP unit.

5.4 - Unit Energy Cost

The unit energy cost can be derived as follows.

Unit energy cost equals

$$\frac{\text{Total cost of energy production over 15 years}}{\text{Total energy produced in 15 years}}$$

From Table 5.1, the total cost of energy production over 15 years equals $2,072,6000.

- Energy produced (net energy recoverable) by the CHP unit per year equals

5 M Btu/h x 7,500 h/a = 37 500 M Btu/a

- Energy produced (net energy recoverable) by the CHP unit in 15 years equals

37 500 M Btu/a x 15 years = 562 500 M Btu

equals

164 814 500 kW•h

The unit energy cost equals

$$\frac{\$2,072,600}{164\ 812\ 500\ kW•h} = 12.5\ Mills/kW•h$$

5.5 - Benefits

The operation of the chemical heat pump will provide economic savings in the form of reduced energy requirements. The recovery of waste heat will replace a portion of the natural gas (or fuel oil) normally required to fuel boilers.

In Section 5.1, it was estimated that the proposed chemical heat pump would recover heat energy equivalent to about (2.07 G cal/h) 8 200 000 Btu/h of fuel energy. The operating capacity factor for the chemical heat pump is assumed to average about 85 percent (7,500 h/a).

The current price of gas supplied to large industries in Southern Ontario, on an interruptible basis, is approximately ($17.86/G cal) $4.50/M Btu. The price of gas is assumed to increase at a real rate of 2 percent annually. Annual energy savings would range from $300,000 to $380,000 over the 15-year life of the project.

Since the design, construction and installation phases are projected to take 24 months, the operation of the chemical heat pump will not produce savings until the third year. In the first year of operation the heat pump is assumed to have a 20 percent reduction in output (and savings) as a result of the commissioning phase.

5.6 - Results of the Economic Analysis

Table 5-1 shows the annual net cash flow of the project over a 17-year period (2 years for design/construction and 15 years of operation). The total capital cost is almost equally split during the 2 years before start-up. Refer to Section 5.2 and Section 6 regarding separate cost elements and the timing of investment costs.

The operating costs have two components: electrical power and labor (the latter includes operation, maintenance and incidental materials). Although the labor cost assumes one full-time operator, it was assumed that the operator will also spend most of his time on normal plant operations (which is seen as a benefit). Therefore, the figure of $12,000/a is the net cost of labor.

The calculations in Table 5-1 show that the chemical heat pump will provide a positive cash flow in every year of operation. The cumulative net present value (NPV) of annual cash flow suggests a payback period of 8.3 years after construction is completed. This payback is based on a real discount rate of 10 percent. Assuming inflation was 6 percent, this discount rate would equate to a minimum required return on investment of 16 percent.

TABLE 5.1

ECONOMIC ANALYSIS OF CHEMICAL HEAT PUMP

2% REAL ESCALATION OF FOSSIL FUEL

YEAR	CAPITAL COST ($000) ENG/MGMT	EQUIP	CONSTR	IDC(6%)	CONTGY.	OPERATING COST($000) POWER	LABOUR	TOTAL COST ($000)	ENERGY PRICE ($/MBtu)	BENEFITS ($000) ENERGY	NET CASH FLOW ($000)
1	180	369		32.9	46.6			628.5	4.50	0.0	-628.5
2	90	305	155	33.0	46.6			629.6	4.59	0.0	-629.6
3						42.3	12	54.3	4.68	230.3	176.0
4						42.3	12	54.3	4.78	293.7	239.4
5						42.3	12	54.3	4.87	299.6	245.3
6						42.3	12	54.3	4.97	305.6	251.3
7						42.3	12	54.3	5.07	311.7	257.4
8						42.3	12	54.3	5.17	317.9	263.6
9						42.3	12	54.3	5.27	324.3	270.0
10						42.3	12	54.3	5.38	330.7	276.4
11						42.3	12	54.3	5.49	337.4	283.1
12						42.3	12	54.3	5.60	344.1	289.8
13						42.3	12	54.3	5.71	351.0	296.7
14						42.3	12	54.3	5.82	358.0	303.7
15						42.3	12	54.3	5.94	365.2	310.9
16						42.3	12	54.3	6.06	372.5	318.2
17						42.3	12	54.3	6.18	379.9	325.6

BASE CASE RESULTS

YEAR	INTERNAL RATE OF RETURN	CUMULATIVE NPV @ 10% ($000)
1	16.61	-571.4
2		-1091.7
3		-959.5
4		-796.0
5		-643.7
6		-501.8
7		-369.8
8		-246.8
9		-132.3
10		-25.7
11		73.5
12		165.8
13		251.8
14		331.7
15		406.2
16		475.4
17		539.8

DISCOUNT RATE SENSITIVITY

YEAR	CUMULATIVE NPV @ 7% ($000)	CUMULATIVE NPV @ 13% ($000)
1	-587.4	-556.2
2	-1137.3	-1049.3
3	-993.6	-927.3
4	-811.0	-780.5
5	-636.1	-647.3
6	-468.7	-526.7
7	-308.4	-417.3
8	-155.0	-318.1
9	-8.2	-228.2
10	132.4	-146.8
11	266.8	-73.0
12	395.5	-6.2
13	518.6	54.4
14	636.4	109.3
15	749.1	159.0
16	856.9	204.0
17	959.9	244.8

20 % REDUCTION OF CAPITAL COSTS

YEAR	NET CASH FLOW ($000)	INTERNAL RATE OF RETURN	CUMULATIVE NPV @ 10% ($000)
1	-502.6	20.81	-456.9
2	-509.4		-877.9
3	176.0		-745.6
4	239.4		-582.1
5	245.3		-429.8
6	251.3		-288.0
7	257.4		-155.9
8	263.6		-33.0
9	270.0		81.5
10	276.4		188.1
11	283.1		287.3
12	289.8		379.6
13	296.7		465.6
14	303.7		545.6
15	310.9		620.0
16	318.2		689.2
17	325.6		753.6

A payback of 8.3 years is longer than most firms would require for such a capital investment, particularly in the present economic climate. In the longer run, projects with a payback period of 5 years are normally acceptable. This project could prove feasible if the capital cost were reduced or deferred until energy savings began (see Section 5.6.1).

The internal rate of return for this project would be 16.6 percent. By this criteria the project appears marginally viable. That is because the chemical heat pump provides substantial long-term benefits which offset the high initial investment cost. By the end of its economic life, the chemical heat pump will have generated a net present value of $540,000 (at a real discount rate of 10 percent).

5.6.1 - Sensitivity Analysis

The choice of the discount rate for economic analysis varies between individual firms. A change in the discount rate can easily effect the outcome of the feasibility analysis. Given alternative real discount rates of 7 and 13 percent, the resulting payback periods for the base case would be 7.1 and 10.1 years, respectively, and the net present value of the project would range from a high of $960,000 to a low of $245,000.

Cost assistance of any kind will significantly improve the financial feasibility of this project. A reduction of the capital cost by 20 percent would increase the capital internal rate of return from 16.6 percent to 20.8 percent. Using a real discount rate of 10 percent, the project would payback in 6.3 years and have a net present value of $754,000.

The capital cost estimate for the proposed CHP unit is considered relatively high. This is primarily due to the front-end costs associated with research and development of the CHP unit. It is anticipated that CHP equipment cost will likely be reduced in the near future when commercial installations are realized.

6 - TYPICAL DEMONSTRATION PROJECT IMPLEMENTATION SCHEDULE

There are several alternative management approaches in the implementation of a demonstration project, namely

(1) Turn key approach - a specification is prepared covering the entire installation and the work awarded to a single contractor who supplies all equipment and material, provides the detailed engineering and manages the project. This has the attraction in that it involves one contract and thus one responsibility only, resulting in some cost saving. It also requires a minimum of administration on the part of the owner. However, it has the disadvantage that the technical and cost control on the project largely lies with the Contractor.

(2) Complete project engineering and management by a consultant - separate specifications are prepared by a consultant for the procurement of equipment and material. The erection contracts are awarded by tendering to a single or several contractors and supervised and managed by the consultant. This has the disadvantage in that the amount of administration work will be heavier on the part of the owner or his consultant. The advantage of this approach is that the owner, directly or through his consultant, would retain complete control of the technical and cost respects of the project.

(3) A combination of (1) and (2) above - the consultant designs the plant, procures by normal tendering process the critical items. The consultant than prepares a single tender document to cover procurement of the balance of the equipment and material, construction of the facilities and installation of the owner-supplied critical equipment. This approach has the advantage that the owner retains technical and cost control while, at the same time, the need for his involvement in detail administration is reduced considerably.

The objectives for a demonstration project demand that the owner (or/and sponsor) must retain complete control on the project both in technical and cost aspects of the work in order to enable him to compile implementation and experimental data for further evaluation. While it is envisaged that a pure turn key approach may not be appropriate, it is recognized that the chemical heat pump equipment remains to be the key element and most critical item of this project and the CHP equipment supplier's (and/or contractor) involvement must not be neglected.

An approach which embodies both turn key and owner/consultant managed elemented as described in (3) above appears therefore most attractive for the demonstration project.

A typical implementation schedule is shown in Figure 6-1, to identify the 'Engineering and Design', 'Construction', 'Commissioning' and 'Experimental Operation' phases of the project.

6.1 - Engineering and Design

This phase of work will include four major tasks.

(a) Environmental Reassessment

The proposal of sulphuric acid heat pump has already caused concern to many industry establishments. Environmental and safety-related concern will be reassessed and the use of alternative chemicals will be reevaluated. Recommendations on safety measures, corrosion protection and suitable material will be highlighted and incorporated into the detail design.

(b) Project Design Outline

A project design document will be prepared to outline the design objectives and criteria, critical and major equipment performance

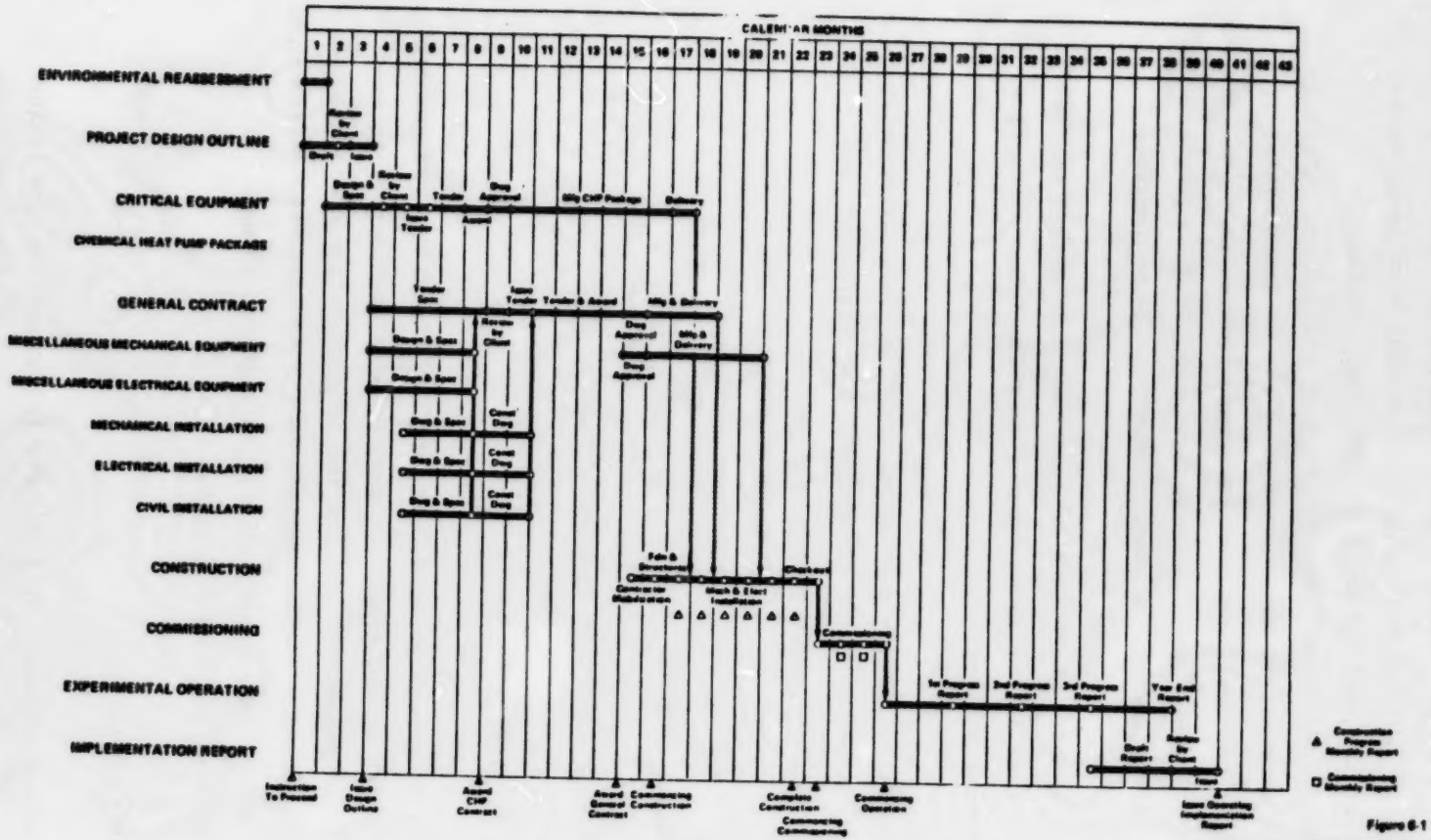


Figure 6-1

CHEMICAL HEAT PUMP STUDY
DEMONSTRATION PROJECT IMPLEMENTATION SCHEDULE
DSS File No. 01SX 31926-3-3060
Acres Project No. P7083.00

required, specification and drawing requirement, project capital cost estimate, the project organization, and a project schedule. This document will be issued for the owner's review comment and approval and will become the base document for the detail engineering and design.

(c) Critical Equipment Specification

The critical equipment in this project will undoubtedly be the chemical heat pump package. A tender specification document will be prepared as soon as the engineering and design phase is initiated. The document will cover a packaged CHP unit including evaporator, absorber, generator, condensor, acid heat exchangers, circulating pumps and control panel completely shop fabricated for field installation.

The tender document will be reviewed and approved by the owner prior to tender call. The tenders received will be evaluated for equipment efficiency versus final cost. After approval of the selection from the owner, a contract will be awarded to the selected supplier.

(d) General Contract

Concurrent with the purchase of the CHP package, tender document will be prepared to cover the supply of the balance of equipment and material, construction of foundations and structures, installation of the CHP package and the complete mechanical and electrical systems.

The level of detail provided in the tendering document will be sufficient that the Contractor is able to proceed construction work without delay. Information provided will generally include

- design data and drawings for the CHP unit

- engineering design standard for the complete work

- piping, ducting and instrument diagrams and detail drawings

- general arrangement drawings of the total system

- single line diagram and wiring design of the electrical system

- technical specification for miscellaneous mechanical and electrical equipment

- technical specifications for pipe ducting, instrument, cabling and wiring system

- technical specification for foundation, structures and other civil-related work.

Vendor quality assurance and expediting activities were not shown in Figure 6.1, but will be included in the 'Engineering and Design' phase of work.

6.2 - Construction

Construction will be directly coordinated by the owner or through a consultant. A construction manager will be appointed from the owner's or the consultant's staff.

The Construction Manager would be responsible for directing and coordinating the work of all the contractors to ensure that the work is carried out expeditiously and in accordance with the contract drawings and specifications. He would exercise progress and job control and certify payments of invoices for equipment, materials and labor. Records would be maintained to monitor commitments, costs and variances due to design changes and field change notices.

The work would include coordination of field construction with the equipment suppliers and the plant designers through the engineers' and manufacturers' representatives at the site. This is to ensure that the drawings and specifications reflect current site conditions and that the equipment is fabricated and shipped as required to meet the project schedule requirements; also to ensure that equipment, system and site interfaces are correctly maintained.

Monthly construction progress will be provided by the construction manager during this phase of the work.

6.3 - Commissioning

Commissioning is the process of provisionally accepting the completed plant and equipment from the contractor on behalf of the owner and directing and supervising trial operation until the plant is finally accepted and put into experimental operation.

The direction and supervision would be carried out by the owners or the consultants commissioning engineer.

Commissioning should generally include

- witnessing of cleaning and testing (hydraulic, air and mechanical) equipment and piping. Validation of piping, electrical and instrument circuits against line installation diagrams

- arranging for the CHP equipment supplier and contractors to put into mechanical operation the individual equipment items and system circuits and witnessing of performance tests

- arranging for the placing of all equipment in readiness for start-up and in conjunction with the owner's staff, bringing each system in sequence into full satisfactory operation

- certification that plant and equipment is acceptable for trial operation and that interim payment to the contractor is due, if applicable

- certification that plant and equipment is acceptable for experimental operation and that final payment is due.

The commissioning engineer would document the provisional acceptance of plant and equipment for trial operation and will coordinate the owner's operating personnel and the continuing work of the contractors and subcontractors so that the trial operation of equipment can proceed safely. Once the plant has been accepted for trial operation, contractors and subcontractors will not be permitted to be on site in order to rectify or complete work, without notification of the operators and the approval of the commissioning engineer and only after verification that the procedures are safe. Operating and maintenance manuals will be assembled, reviewed and approved for use during this stage.

Monthly commissioning program reports will also be provided by the commissioning engineer to all concerned parties.

6.4 - Experimental Operation

This phase of the project work will essentially be carried out by the owner's operating staff. It will be of upmost importance that experimental operating data be documented in a systematic manner and quarterly reports be issued to all concerned parties.

It is expected that the experimental operation period will be approximately 12 months so as to permit sufficient time for observations of the CHP performance.

Upon the completion of the demonstration project, a completion report should be prepared by the project staff with contributions from all levels of participants.

The duration of this demonstration project is estimated to be approximately 40 months, consisting of

Engineering and design	10 months
Manufacturing and Delivery	6 months
Construction and check out	8 months
Commissioning	3 months
Experimental operation	13 months

7 - SURVEY OF CANADIAN INDUSTRY POTENTIAL FOR CHEMICAL HEAT PUMP APPLICATION

Essentially, energy consumed by industry is either transformed to a non-useful form, becomes embodied in the manufactured products, or rejected as gaseous or liquid waste heat streams.

Rejected energy is defined as energy consumption less non-heat requirements. Rejected heat streams are defined as rejected energy less process, product and heating losses.

Non-heat requirements include all non-process uses such as transportation, lighting and mechanical drive, which produce useful work, non-useful work and friction losses. In the few cases where recoverable energy from non-heat uses could be identified, for example, the cooling water from compressors and refrigeration units, they were included in the appropriate rejected energy stream.

The Process, Product and Heating Losses category includes all unidentifiable losses of heat from processes, products, building surfaces, space heating and cooling systems. It includes the net available energy required to complete endothermic reactions, plus all other losses such as convection losses and sensible heat in the product. It also includes heat radiation losses from hot process and product surfaces, mechanical equipment, piping and ductwork. The dispersed nature of these losses make them unsuitable for waste heat recovery, although other conservation techniques may be applicable.

The electricity produced by the Electric Power industry, both base-load and stand-by, is included in the Process, Product and Heating Losses category. The energy produced is not actually lost or rejected, but is in effect 'the product'.

The temperature and quality of rejected heat streams varies considerably between industries and even between companies in the same industry, depending on the specific complement of industrial processes and

equipment. However, there are only three principal sources of rejected heat:

1. Combustion equipment which exhaust flue gases at relatively high temperatures and electrolytic processes with high temperature emissions.

   Higher than 290°C (550°F) - primarily furnace and kiln flue gases

   100°C - 290°C (212°F - 550°F) - primarily boiler flue gases

2. Definable process losses, generally liquids at moderate to low temperatures, but occasionally gaseous and solid product materials.

3. Gas turbines and diesel engines (used for a variety of purposes such as power generation, refrigeration, etc) which have high temperature gaseous exhausts and cooling water streams.

There are probably no streams of rejected heat with temperatures above 815°C (1,500°F). While there are cases where heat leaves process equipment (such as furnaces) above 815°C (1,500°F), it is invariably already cascaded, through the use of a waste heat recovery boiler, or it is infiltrated with low temperature air to render it treatable by conventional emission quality control equipment.

Most of the current available chemical heat pumps are designed to elevate temperatures up to about 118°C (230°F). Sulphuric acid gas-liquid chemical heat pumps are capable of elevating temperature up to 205°C (400°F), while gas-solid such as zeolite and clay mineral and metal hydrides heat pumps have a potential to up-grading waste heat stream temperature to 205°C - 290°C (400° - 550°F) range. Based on the current chemical heat pump technology, rejected heat stream f 290°C (550°F) or higher are considered, therefore, not feasible for direct chemical heat pump applications.

For the purposes of this survey, it was assumed that the potential for chemical heat pumps application is limited to industry rejected heat streams which are in a temperature range of 32°C - 290°C (90°F - 550°F).

Data published by Lalonde, Girouard, Letendre and Associates Ltd., in a study paper entitled "Energy Cascading Potential in Canadian Industry", December 1981, (Reference 21) has been utilized for this survey. Table 7-1 shows the assumed average temperature of the rejected energy for each industry which forms the basis to determine the potential rejected heat sources for chemical heat pump application.

Table 7-2 shows the potential rejected heat streams by industry for the whole country while Table 7-3 tp 7-13 further lists the data by province.

TABLE 7-1

ASSUMED AVERAGE TEMPERATURES OF REJECTED ENERGY

CODE				AVERAGE TEMPERATURE °F OF REJECTED ENERGY			
Div	MC	SIC	INDUSTRY	> 550°F	212-550°F	120-212°F	< 120°F
2	01	031	Logging	-	400	150	-
4			Mining	-	450	150	-
5			Manufacturing Industries	600	400	150	100
	01		Food and Beverage	600	400	150	100
		101	Meat and Poultry	-	400	150	100
		104	Dairy	-	400	150	100
		107	Bakery	600	400	150	100
		109	Beverage	600	400	150	100
			Other Food and Beverage	600	400	150	100
	02		Tobacco	-	400	150	100
	03		Rubber and Plastics	600	400	150	100
	04		Leather	-	400	150	100
	05		Textiles	650	400	-	100
		183	Man-made Fibres	550	400	-	100
			Other Textiles	550	400	-	100
	06		Knitting Mills	550	400	150	100
	07		Clothing	550	400	150	100
	08		Wood Products	-	450	150	100
	09		Furniture and Fixtures	-	400	150	100
	10		Paper and Allied Products	-	400	165	100
		271	Pulp and Paper Mills	-	400	165	100
			Other Paper and Allied	-	400	165	100
	11		Printing, Publishing and Allied Products	-	-	150	100
	12		Primary Metals	-	450	150	100
		291	Iron and Steel Mills	-	450	150	100
		295	Smelting and Refining	-	450	150	100
			Other Primary Metallic	-	450	150	100
	13		Metal Fabricating	600	450	150	100
	14		Machinery	700	450	150	100
	15		Transportation Equipment	600	400	150	100
	16		Electrical Products	600	400	150	100
	17		Non-metallic Mineral Pro.	750	450	150	-
		352	Cement	750	450	150	-
		356	Glass	750	450	150	-
			Other Non-metallic	750	450	150	-
	18		Petroleum and Coal Products	600	450	150	-
		3651	Petroleum Refining	600	450	150	-
			Other Petroleum	600	450	150	-
	19		Chemical and Chemical Pro.	600	450	150	100
		378	Industrial Chemicals	600	450	150	100
			Other Chemicals	600	450	150	100
7	20		Miscellaneous Manufact.	600	450	150	100
	04	572	Electric Power; Base Load	550	375	150	100
			Standby	550	375	150	100

TABLE 7-2

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
CANADA - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	48,7	169,0	-	0,87	2,06	-
4			Mining	43,898,3	6,874,3	-	790,17	838,66	-
5			Manufacturing Industries	383,098,7	123,886,7	182,836,0	6,895,77	15,114,17	36,567,20
	01		Food and Beverage	12,443,3	2,883,7	29,069,4	223,97	351,81	5,813,88
		101	Meat and Poultry	1,055,3	1,055,3	5,279,5	18,99	128,75	1,055,9
		104	Dairy	887,8	1,331,9	3,552,8	15,98	162,49	710,56
		107	Bakery	265,1	88,0	884,5	4,77	10,73	176,9
		109	Beverage	2,687,4	127,4	5,119,2	48,21	15,54	1,023,04
			Other Food and Beverage	7,547,7	281,1	14,233,4	135,85	34,29	2,846,68
	02		Tobacco	168,4	79,0	189,1	3,03	9,63	37,82
	03		Rubber and Plastics	699,7	487,3	881,2	12,59	59,45	176,24
	04		Leather	691,9	229,9	460,4	12,45	28,04	92,08
	05		Textiles	4,098,2	-	5,137,8	73,76	-	1,027,56
		183	Man-made Fibres	1,544,0	-	2,309,7	27,79	-	461,94
			Other Textiles	2,554,2	-	2,828,1	45,97	-	565,62
	06		Knitting Mills	497,5	194,7	281,4	8,95	23,75	56,28
	07		Clothing	268,9	298,7	390,4	4,84	36,44	78,08
	08		Wood Products	1,984,7	1,099,6	725,3	35,72	134,15	145,06
	09		Furniture and Fixtures	833,0	275,1	830,2	14,99	33,56	166,04
	10		Paper and Allied Products	139,353,2	36,936,6	117,392,2	2,508,35	4,497,70	23,478,44
		271	Pulp and Paper Mills	138,081,3	36,431,7	117,334,1	2,485,46	4,444,66	23,466,82
			Other Paper and Allied	1,271,9	106,9	58,1	22,89	13,04	11,62
	11		Printing, Publishing	-	261,4	238,5	-	31,89	51,7
			and Allied Products	-	-	-	-	-	1,529,9
	12		Primary Metals	176,790,3	32,203,8	7,649,5	3,182,22	3,928,86	1,493,48
		291	Iron and Steel Mills	105,142,5	24,682,4	7,467,4	1,892,56	3,011,25	20,44
		295	Smelting and Refining	67,154,9	6,729,1	102,2	1,208,78	820,95	15,98
			Other Primary Metallic	4,492,9	792,3	79,9	80,87	96,66	341,08
	13		Metal Fabricating	449,8	5,636,1	2,705,4	8,09	687,60	452,40
	14		Machinery	884,4	2,164,5	2,262,0	15,91	264,06	236,76
	15		Transportation Equipment	1,183,2	6,218,7	1,183,8	21,29	758,68	182,66
	16		Electrical Products	1,013,3	1,824,2	913,3	18,23	222,55	-
	17		Non-metallic Mineral Pro.	22,228,2	3,952,4	-	400,10	482,19	-
		352	Cement	3,659,5	2,250,3	-	65,87	274,53	-
		356	Glass	487,4	1,702,2	-	8,77	207,66	-
			Other Non-metallic	18,081,3	0,1	-	325,46	0,01	-
	18		Petroleum and Coal	-	5,685,5	-	-	693,63	-
			Products	-	5,679,8	-	-	692,93	-
		3651	Petroleum Refining	-	5,7	-	-	0,69	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	18,921,2	23,263,2	11,872,2	340,58	2,838,11	2,374,44
		378	Industrial Chemicals	16,267,2	20,817,2	10,496,4	292,80	2,539,69	2,099,28
			Other Chemicals	2,654,0	2,446,0	1,375,8	47,77	298,41	275,16
7	2C		Miscellaneous Manufact.	595,5	589,5	634,9	10,71	71,91	126,98
	04	572	Electric Power: Base Load	106,700,4	533,8	597,345,4	1,920,60	65,12	119,509,08
			Standby						
			TOTAL	533,748,0	131,312,0	780,381,0	9,607,4	16,020,0	156,076,2

TABLE 7-3

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
NEWFOUNDLAND - 1978

(Btu x 10^9)

CODE			INDUSTRY	REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC		212°F to 350°F	120°F to 212°F	< 120°F	212°F to 350°F	120°F to 212°F	< 120°F
2	01	031	Logging	-	-	-	-	-	-
4			Mining	7,166,8	1,102,5	-	129,00	16,40	-
5			Manufacturing Industries	3,197,7	1,430,6	2,801,6	57,56	174,53	560,32
	01		Food and Beverage	177,8	9,0	342,4	3,20	1,09	68,48
		101	Meat and Poultry	-	-	-	-	-	-
		104	Dairy	-	-	-	-	-	-
		107	Bakery	2,4	0,8	8,2	0,04	0,09	1,64
		109	Beverage	37,0	1,7	70,5	0,66	0,20	14,10
			Other Food and Beverage	138,4	6,5	263,7	2,49	0,79	52,74
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	-	-	-	-	-	-
	04		Leather	-	-	-	-	-	-
	05		Textiles	-	-	-	-	-	-
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	-	-	-	-	-	-
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	-	-	-	-	-	-
	08		Wood Products	5,3	3,1	2,1	0,09	0,31	0,42
	09		Furniture and Fixtures	-	-	-	-	-	-
	10		Paper and Allied Products	2,645,3	1,183,2	2,399,9	47,62	144,35	479,98
		271	Pulp and Paper Mills	2,641,7	1,181,5	2,396,5	47,55	144,14	479,30
			Other Paper and Allied	3,8	1,7	3,4	0,06	0,20	0,68
	11		Printing, Publishing	-	0,2	0,2	-	0,20	0,04
			and Allied Products			-	-	-	-
	12		Primary Metals	-	-	-	-	-	-
		291	Iron and Steel Mills	-	-	-	-	-	-
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	0,6	8,4	4,0	0,01	1,02	0,8
	14		Machinery	-	-	-	-	-	-
	15		Transportation Equipment	-	-	-	-	-	-
	16		Electrical Products	-	-	-	-	-	-
	17		Non-metallic Mineral Pro.	109,5	-	-	1,97	-	-
		352	Cement	50,5	-	-	0,90	-	-
		356	Glass	-	-	-	-	-	-
			Other Non-metallic	59,5	-	-	1,07	-	-
	18		Petroleum and Coal	-	-	26,8	-	-	5,36
			Products	-	-	26,8	-	-	5,36
		3651	Petroleum Refining	-	-	-	-	-	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	259,0	205,9	53,0	4,66	25,11	10,6
		378	Industrial Chemicals	259,0	205,9	53,0	4,66	25,11	10,6
			Other Chemicals	-	-	-	-	-	-
	20		Miscellaneous Manufact.	-	-	-	-	-	-
7	04	572	Electric Power; Base Load	1,576,5	168,2	4,221,6	28,37	20,52	844,32
			Standby						
			TOTAL	11,941,0	2,707,0	7,023,0	214,94	330,75	1,404,6

TABLE 7-4

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
PRINCE EDWARD ISLAND - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	-	-	-	-	-	-
4			Mining	-	-	-	-	-	-
5			Manufacturing Industries	88.6	20.5	197.1	1.59	2.30	39.42
	01		Food and Beverage	88.1	23.8	196.3	1.58	2.90	39.26
		101	Meat and Poultry	-	-	-	-	-	-
		104	Dairy	13.5	20.3	54.2	0.24	2.30	10.84
		107	Bakery	-	-	-	-	-	-
		109	Beverage	-	-	-	-	-	-
			Other Food and Beverage	76.4	3.5	142.1	1.37	0.42	28.42
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	-	-	-	-	-	-
	04		Leather	-	-	-	-	-	-
	05		Textiles	-	-	-	-	-	-
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	-	-	-	-	-	-
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	-	-	-	-	-	-
	08		Wood Products	-	-	-	-	-	-
	09		Furniture and Fixtures	-	-	-	-	-	-
	10		Paper and Allied Products	-	-	-	-	-	-
		271	Pulp and Paper Mills	-	-	-	-	-	-
			Other Paper and Allied	-	-	-	-	-	-
	11		Printing, Publishing	-	0.2	0.3	-	0.02	0.06
			and Allied Products			-	-	-	-
	12		Primary Metals	-	-	-	-	-	-
		291	Iron and Steel Mills	-	-	-	-	-	-
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	-	-	-	-	-	-
	14		Machinery	-	-	-	-	-	-
	15		Transportation Equipment	0.3	2.1	0.4	0	0.25	0.08
	16		Electrical Products	-	-	-	-	-	-
	17		Non-metallic Mineral Pro.	-	-	-	-	-	-
		352	Cement	-	-	-	-	-	-
		356	Glass	-	-	-	-	-	-
			Other Non-metallic	-	-	-	-	-	-
	18		Petroleum and Coal	-	-	-	-	-	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	-	-	-	-	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	0.2	0.4	0.1	0	-	0.02
		378	Industrial Chemicals	-	-	-	-	-	-
			Other Chemicals	0.2	0.4	0.1	0	-	0.02
	20		Miscellaneous Manufact.	-	-	-	-	-	-
7	04	572	Electric Power; Base Load	633.7	-	1,038.6	11.40	-	327.72
			Standby						
			TOTAL	722.0	27.0	1,836.0	12.99	3.29	367.2

TABLE 7-5

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
NOVA SCOTIA - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	0,2	-	-	0	-	-
4			Mining	258,4	43,0	-	4,65	5,24	-
5			Manufacturing Industries	13,673,2	5,334,4	5,611,6	246,11	675,19	1,122,32
	01		Food and Beverage	267,0	39,8	562,7	4,80	4,85	112,54
		101	Meat and Poultry	6,6	6,6	33,4	0,11	0,80	6,68
		104	Dairy	13,9	20,8	55,6	0,25	2,33	11,12
		107	Bakery	2,8	0,9	9,5	0,05	0,10	1,9
		109	Beverage	55,7	2,6	106,1	1,00	0,32	21,22
			Other Food and Beverage	188,0	8,9	338,1	3,38	1,08	7,162
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	-	-	-	-	-	-
	04		Leather	-	-	-	-	-	-
	05		Textiles	67,7	-	85,9	1,21	-	17,18
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	69,7	2,0	87,9	1,25	0,24	17,58
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	1,0	1,2	1,4	0,01	0,14	0,28
	08		Wood Products	20,8	13,3	7,5	0,37	1,62	1,5
	09		Furniture and Fixtures	3,4	1,0	3,4	0,06	0,12	0,68
	10		Paper and Allied Products	4,424,9	1,176,0	3,169,2	79,64	143,47	633,84
		271	Pulp and Paper Mills	4,384,8	1,165,3	3,140,5	78,92	142,16	628,1
			Other Paper and Allied	40,1	10,7	28,7	0,72	1,30	5,74
	11		Printing, Publishing	-	1,2	1,3	-	0,14	0,26
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	6,523,6	1,586,8	176,3	117,42	193,58	35,26
		291	Iron and Steel Mills	6,523,6	1,586,8	176,3	117,42	193,58	35,26
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	2,8	35,6	17,3	0,05	4,34	3,46
	14		Machinery	-	-	-	-	-	-
	15		Transportation Equipment	25,7	134,9	25,7	0,46	16,45	5,14
	16		Electrical Products	5,4	9,8	4,8	0,09	1,19	0,96
	17		Non-metallic Mineral Pro.	264,2	-	-	4,76	-	-
		352	Cement	117,3	-	-	2,11	-	-
		356	Glass	-	-	-	-	-	-
			Other Non-metallic	146,9	-	-	2,64	-	-
	18		Petroleum and Coal	-	468,1	-	-	57,1	-
			Products	-	468,1	-	-	57,1	-
		3651	Petroleum Refining	-	-	-	-	-	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	2,066,7	2,066,7	1,556,1	37,20	252,13	311,22
		378	Industrial Chemicals	2,066,7	2,066,7	1,556,1	37,20	252,13	311,22
			Other Chemicals	2,3	2,3	1,7	0,04	0,28	0,34
	20		Miscellaneous Manufact.	-	-	-	-	-	-
7	04	572	Electric Power; Base Load	9,195,6	30,9	16,296,6	165,52	3,76	3,299,32
			Standby						
			TOTAL	23,127,0	5,608,0	21,908,0	416,28	684,17	4,381,6

TABLE 7-6

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
NEW BRUNSWICK - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	1,3	-	-	0,02	-	-
4			Mining	796,7	122,3	-	14,34	14,94	-
5			Manufacturing Industries	11,849,4	2,785,1	11,774,8	213,29	339,78	2,354,96
	01		Food and Beverage	656,3	53,8	1,298,8	11,81	6,56	259,76
		101	Meat and Poultry	4,9	4,9	24,9	0,08	0,59	4,98
		104	Dairy	11,0	16,6	44,3	0,20	2,02	8,86
		107	Bakery	6,7	2,2	22,3	0,12	0,26	4,46
		109	Beverage	54,6	2,6	104,1	0,98	0,31	20,82
			Other Food and Beverage	379,1	27,5	1,103,2	10,42	3,35	220,64
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	-	-	-	-	-	-
	04		Leather	-	-	-	-	-	-
	05		Textiles	1,4	-	2,4	-	-	0,48
		183	Man-made Fibres	-	-	-	-	-	0,98
			Other Textiles	3,4	2,0	4,4	0,02	0,24	-
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	-	-	-	-	-	-
	08		Wood Products	62,0	40,1	18,9	1,11	4,89	3,78
	09		Furniture and Fixtures	6,8	2,1	6,8	0,12	0,24	1,36
	10		Paper and Allied Products	9,195,7	2,058,9	10,042,7	165,52	251,16	2,008,5
		271	Pulp and Paper Mills	9,179,5	2,053,3	10,025,-	165,23	250,50	2,005,0
			Other Paper and Allied	16,2	3,6	17,7	0,29	0,43	3,54
	11		Printing, Publishing	-	1,2	1,2	-	0,14	0,24
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	1,175,8	-	50,4	21,16	-	10,08
		291	Iron and Steel Mills	-	-	-	-	-	-
		295	Smelting and Refining	1,148,9	-	88,3	20,68	-	17,66
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	4,0	54,7	25,9	0,07	6,67	5,18
	14		Machinery	1,8	4,3	4,3	0,03	0,52	0,86
	15		Transportation Equipment	0,3	2,0	0,3	0	0,24	0,06
	16		Electrical Products	-	-	-	-	-	-
	17		Non-metallic Mineral Pro.	653,8	49,3	-	11,77	6,01	-
		352	Cement	122,5	-	-	2,20	-	-
		356	Glass	24,6	49,3	-	0,44	6,01	-
			Other Non-metallic	506,7	-	-	9,12	-	-
	18		Petroleum and Coal	-	396,7	-	-	48,39	-
			Products	-	396,7	-	-	48,39	-
		3651	Petroleum Refining	-	-	-	-	-	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	85,1	117,6	276,3	1,53	14,34	55,26
		378	Industrial Chemicals	73,0	101,4	233,6	1,31	12,37	46,72
			Other Chemicals	12,1	16,1	42,7	0,21	1,97	8,54
	20		Miscellaneous Manufact.	6,4	6,4	6,8	0,11	0,78	1,36
7	04	572	Electric Power: Base Load	9,658,0	22,2	23,393,9	173,84	2,70	4,678,78
			Standby						
			TOTAL	22,305,0	2,930,0	35,169,0	401,49	357,46	7,033,80

TABLE 7-7

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
QUEBEC - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	12,0	3,9	-	0,21	0,47	-
4			Mining	11,398,0	1,753,5	-	205,16	213,92	-
5			Manufacturing Industries	93,467,5	25,732,3	39,196,6	1,682,41	2,143,00	1,567,86
	01		Food and Beverage	2,508,5	949,2	6,501,3	45,15	115,80	1,300,26
		101	Meat and Poultry	247,7	247,7	1,238,9	4,45	30,21	247,18
		104	Dairy	389,9	384,8	1,359,7	7,01	71,34	311,94
		107	Bakery	97,1	32,3	323,9	1,74	3,94	64,78
		109	Beverage	674,8	32,1	1,285,5	12,14	3,94	257,10
			Other Food and Beverage	1,099,0	32,3	2,093,3	19,78	6,38	418,66
	02		Tobacco	75,8	37,9	87,2	1,346	4,62	17,44
	03		Rubber and Plastics	162,5	107,4	209,7	2,92	13,10	41,94
	04		Leather	82,2	27,1	53,6	1,48	3,30	10,72
	05		Textiles	1,878,7	-	2,360,7	33,81	-	472,14
		183	Man-made Fibres	69,6	-	419,8	1,25	-	83,96
			Other Textiles	1,809,1	-	1,940,9	32,56	-	388,18
	06		Knitting Mills	222,4	87,0	125,7	4,00	10,61	25,14
	07		Clothing	92,7	103,0	135,0	1,67	12,56	27,0
	08		Wood Products	176,4	113,6	82,8	3,17	13,86	16,56
	09		Furniture and Fixtures	253,8	84,6	253,8	4,56	10,32	50,76
	10		Paper and Allied Products	27,516,4	12,820,1	26,578,4	495,29	1,564,05	5,315,68
		271	Pulp and Paper Mills	27,183,4	12,819,4	26,565,6	489,30	1,563,96	5,313,12
			Other Paper and Allied	333,0	0,7	12,8	5,49	0,08	2,56
	11		Printing, Publishing	-	63,6	61,5	-	7,76	12,30
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	51,533,7	5,025,3	-	927,60	613,08	-
		291	Iron and Steel Mills	12,381,1	1,031,7	-	222,85	125,86	-
		295	Smelting and Refining	38,382,4	3,936,1	-	690,88	480,26	-
			Other Primary Metallic	770,2	57,0	-	13,86	6,95	-
	13		Metal Fabricating	83,4	1,043,4	500,8	1,50	127,29	100,16
	14		Machinery	144,1	352,3	368,3	2,59	42,98	73,66
	15		Transportation Equipment	152,8	802,6	152,8	2,75	97,91	30,56
	16		Electrical Products	222,9	401,2	200,6	4,01	48,94	40,16
	17		Non-metallic Mineral Pro.	5,243,0	510,5	-	94,37	62,28	-
		352	Cement	1,593,9	-	-	28,69	-	-
		356	Glass	-	510,5	-	-	62,28	-
			Other Non-metallic	3,649,1	-	-	65,68	-	-
	18		Petroleum and Coal	-	1,770,3	-	-	215,97	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	1,761,1	-	-	214,85	-
			Other Petroleum	-	9,2	-	-	1,12	-
	19		Chemical and Chemical Pro.	2,973,5	1,288,5	1,387,6	53,52	157,19	277,52
		378	Industrial Chemicals	1,767,2	765,7	824,7	31,80	93,41	164,94
			Other Chemicals	1,206,3	522,8	562,9	21,71	63,78	112,58
7	20	...	Miscellaneous Manufact.	144,7	144,7	155,8	2,60	17,65	31,16
	04	572	Electric Power; Base Load	329,5	252,1	346,7	5,93	30,75	69,34
			Standby	-	-	-	-	-	-
TOTAL				105,207,0	27,742,0	39,542,0	1,893,72	3,384,52	7,908,40

TABLE 7-8

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
ONTARIO - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	5,9	1,9	-	0,10	0,23	-
4			Mining	12,576,1	1,934,7	-	226,37	236,03	-
5			Manufacturing Industries	154,314,8	63,991,1	56,640,3	2,777,66	8,050,91	11,328,06
	01		Food and Beverage	5,135,1	1,006,1	11,540,7	42,43	122,74	2,303,14
		101	Meat and Poultry	317,0	317,0	1,585,1	5,70	38,67	317,02
		104	Dairy	249,3	441,5	1,177,4	5,24	53,86	235,48
		107	Bakery	112,9	37,6	376,3	2,03	4,59	75,26
		109	Beverage	1,118,5	53,2	2,150,6	20,13	6,49	426,12
			Other Food and Beverage	3,292,4	156,7	6,271,3	59,26	19,11	1,254,26
	02		Tobacco	93,6	41,9	101,9	1,66	5,11	20,38
	03		Rubber and Plastics	438,6	315,5	561,7	7,89	38,49	112,34
	04		Leather	527,5	175,8	351,7	9,49	21,44	70,34
	05		Textiles	2,087,7	-	2,615,1	37,57	-	523,02
		183	Man-made Fibres	1,276,1	-	1,593,3	22,96	-	318,66
			Other Textiles	811,6	-	1,021,8	14,60	-	204,36
	06		Knitting Mills	234,3	91,7	132,4	4,21	11,18	26,48
	07		Clothing	111,1	123,4	161,1	1,99	15,05	32,22
	08		Wood Products	300,7	240,5	250,3	5,41	29,34	30,06
	09		Furniture and Fixtures	481,1	160,3	481,1	8,66	19,55	96,22
	10		Paper and Allied Products	28,264,1	8,495,7	21,566,1	508,75	1,036,47	4,313,22
		271	Pulp and Paper Mills	27,952,1	8,367,6	21,375,1	503,14	1,018,40	4,275,02
			Other Paper and Allied	672,0	148,1	191,0	12,09	18,06	38,20
	11		Printing, Publishing	-	140,8	140,8	-	17,17	28,16
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	94,677,4	22,705,8	7,258,1	1,704,19	2,770,10	1,451,62
		291	Iron and Steel Mills	84,678,1	21,774,3	7,258,1	1,524,20	2,656,46	1,451,62
		295	Smelting and Refining	7,363,7	736,3	-	132,54	89,82	-
			Other Primary Metallic	2,635,6	195,2	-	47,44	23,81	-
	13		Metal Fabricating	302,5	3,781,7	1,815,2	5,44	461,36	363,04
	14		Machinery	580,1	1,418,0	1,482,5	10,44	172,99	296,50
	15		Transportation Equipment	941,2	4,941,4	914,2	16,94	602,85	182,84
	16		Electrical Products	734,0	1,321,3	660,6	13,21	161,19	132,12
	17		Non-metallic Mineral Pro.	9,145,5	3,176,0	-	164,62	387,47	-
		352	Cement	-	2,250,3	-	28,69	-	-
		356	Glass	462,8	925,7	-	8,33	112,93	-
			Other Non-metallic	8,661,7	-	-	155,91	-	-
	18		Petroleum and Coal	-	1,382,6	-	-	168,67	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	1,315,6	-	-	166,60	-
			Other Petroleum	-	17,0	-	-	2,07	-
	19		Chemical and Chemical Pro.	9,498,1	16,048,5	6,222,9	170,96	1,957,91	1,244,58
		378	Industrial Chemicals	8,297,8	14,332,7	5,582,2	149,36	1,748,58	1,116,44
			Other Chemicals	1,200,3	1,715,8	640,7	21,60	209,32	128,14
7	20		Miscellaneous Manufact.	424,2	424,2	456,9	7,63	51,75	91,38
	04	572	Electric Power; Base Load	42,062,4	-	415,798,0	757,12	-	83,159,60
			Standby	-	-	-	-	-	-
			TOTAL	208,959,0	67,928,0	472,438,0	3,761,26	8,287,22	94,487,60

TABLE 7-9

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
MANITOBA - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	1,9	1,4	-	0,03	0,17	-
4			Mining	301,4	45,3	-	5,42	5,64	-
5			Manufacturing Industries	7,192,5	2,024,2	4,192,6	129,46	246,95	838,52
	01		Food and Beverage	933,9	208,7	2,241,5	16,81	25,46	448,30
		101	Meat and Poultry	126,0	126,0	630,3	2,26	15,37	126,06
		104	Dairy	29,1	43,6	116,4	0,52	5,32	23,28
		107	Bakery	7,7	2,5	25,9	0,14	0,30	5,18
		109	Beverage	60,8	2,8	115,9	1,09	0,34	23,18
			Other Food and Beverage	710,3	33,8	1,353,0	12,78	4,12	270,60
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	-	-	-	-	-	-
	04		Leather	57,6	18,8	38,7	1,03	2,29	7,74
	05		Textiles	4,8	-	6,1	0,08	-	1,22
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	4,8	-	6,1	0,08	-	1,22
	06		Knitting Mills	8,9	3,5	5,3	0,16	0,43	1,06
	07		Clothing	25,5	28,2	37,0	0,46	3,44	7,40
	08		Wood Products	15,1	9,2	3,8	0,27	1,12	0,76
	09		Furniture and Fixtures	48,9	14,8	45,6	0,88	1,80	9,12
	10		Paper and Allied Products	2,308,43	791,4	1,432,2	41,55	96,55	286,44
		271	Pulp and Paper Mills	1,921,6	784,8	1,422,9	34,58	95,74	284,58
			Other Paper and Allied	386,8	6,6	9,3	6,96	0,80	1,86
	11		Printing, Publishing	-	13,7	13,7	-	1,67	2,74
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	1,917,8	191,7	-	34,52	23,38	-
		291	Iron and Steel Mills	224,5	32,0	-	4,04	3,90	-
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	15,0	187,7	90,1	0,27	22,90	18,02
	14		Machinery	39,3	96,0	110,4	0,70	11,71	20,08
	15		Transportation Equipment	20,8	112,6	21,3	0,37	3,20	4,26
	16		Electrical Products	14,7	26,3	13,7	0,26	-	2,74
	17		Non-metallic Mineral Pro.	1,347,1	-	-	24,24	-	-
		352	Cement	404,6	-	-	7,28	-	-
		356	Glass	-	-	-	-	-	-
			Other Non-metallic	942,5	-	-	16,96	-	-
	18		Petroleum and Coal	-	85,6	-	-	10,44	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	85,6	-	-	10,44	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	430,5	231,8	139,0	7,74	28,28	27,80
		378	Industrial Chemicals	420,8	226,6	135,9	7,57	27,28	27,18
			Other Chemicals	9,7	5,2	3,1	0,17	0,63	0,62
7	20		Miscellaneous Manufact.	4,2	4,2	4,2	0,07	0,51	0,84
	04	572	Electric Power; Base Load	882,4	-	2,402,2	15,88	-	480,44
			Standby	-	-	-	-	-	-
TOTAL				8,378,0	2,072,0	6,595,0	150,80	252,78	1,319,0

TABLE 7-10

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
SASKATCHEWAN - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	5,3	2,0	-	0,09	0,24	-
4			Mining	7,215,4	1,202,5	-	129,87	146,70	-
5			Manufacturing Industries	4,356,9	933,9	4,001,7	78,42	113,93	800,34
	01		Food and Beverage	488,4	68,2	1,079,6	8,79	8,32	215,42
		101	Meat and Poultry	46,0	46,0	230,4	0,83	5,61	46,08
		104	Dairy	-	-	-	-	-	-
		107	Bakery	4,5	1,5	15,0	0,08	0,18	3
		109	Beverage	64,8	3,0	123,4	1,66	0,37	24,68
			Other Food and Beverage	373,1	17,7	710,8	6,71	2,16	142,16
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	0,1	-	0,5	0	-	0,1
	04		Leather	-	-	-	-	-	-
	05		Textiles	0,2	-	0,3	0	-	0,06
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	0,2	-	0,3	0	-	0,06
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	4,7	5,3	6,9	0,08	0,64	1,38
	08		Wood Products	92,5	56,4	22,4	1,66	6,88	4,48
	09		Furniture and Fixtures	0,6	0,6	1,1	0,01	0,07	0,22
	10		Paper and Allied Products	2,595,4	607,5	2,767,1	46,72	74,11	553,42
		271	Pulp and Paper Mills	2,586,9	606,8	2,764,3	46,56	74,02	552,86
			Other Paper and Allied	8,5	0,7	2,8	0,15	0,08	0,56
	11		Printing, Publishing	-	8,2	8,0	-	1,00	1,60
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	720,1	102,8	-	12,96	12,54	-
		291	Iron and Steel Mills	-	-	-	-	-	-
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	720,1	102,8	-	12,96	12,54	-
	13		Metal Fabricating	2,2	31,4	15,7	0,04	3,83	3,14
	14		Machinery	23,8	60,2	63,2	0,43	7,34	12,64
	15		Transportation Equipment	1,9	11,6	1,9	0,03	1,41	0,38
	16		Electrical Products	2,8	5,1	2,6	0,05	0,62	0,52
	17		Non-metallic Mineral Pro.	348,8	-	-	6,28	-	-
		352	Cement	178,2	-	-	3,20	-	-
		356	Glass	-	-	-	-	-	-
			Other Non-metallic	170,6	-	-	3,07	-	-
	18		Petroleum and Coal	-	103,1	-	-	12,38	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	102,9	-	-	12,35	-
			Other Petroleum	-	0,2	-	-	0,02	-
	19		Chemical and Chemical Pro.	75,1	73,2	32,1	1,35	8,93	6,42
		378	Industrial Chemicals	73,2	71,9	31,5	1,31	8,77	6,30
			Other Chemicals	1,9	1,3	0,6	0,03	0,15	0,12
7	20		Miscellaneous Manufact.	0,3	0,3	0,3	0	0 03	0,06
	04	572	Electric Power; Base Load	12,233,1	-	33,083,4	220,35	-	6,616,68
			Standby	-	-	-	-	-	-
TOTAL				23,831,0	2,138,0	37,085,0	428,96	260,83	7,417,0

TABLE 7-11

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
ALBERTA - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	0,5	-	-	0,01	-	-
4			Mining	814,5	135,7	-	14,66	16,55	-
5			Manufacturing Industries	15,940,5	6,055,5	10,745,7	286,93	738,77	214,9
	01		Food and Beverage	1,521,0	368,9	3,744,3	27,38	45,01	748,86
		101	Meat and Poultry	235,6	235,6	1,178,4	4,24	28,74	235,68
		104	Dairy	47,1	70,7	188,7	0,85	8,62	37,74
		107	Bakery	13,1	4,3	43,6	0,23	0,52	8,72
		109	Beverage	323,6	15,4	616,3	5,82	1,88	123,26
			Other Food and Beverage	901,6	42,9	1,717,3	16,23	5,23	343,46
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	22,6	15,1	15,5	0,41	1,84	3,10
	04		Leather	21,0	7,0	14,0	0,38	0,85	2,8
	05		Textiles	4,94	-	57,1	0,89	-	11,42
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	51,4	2,0	59,1	0,92	0,24	11,82
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	27,6	30,6	39,9	0,49	3,73	7,98
	08		Wood Products	244,8	61,7	57,6	4,40	7,52	11,52
	09		Furniture and Fixtures	24,7	7,4	24,7	0,44	0,90	4,94
	10		Paper and Allied Products	5,633,2	542,0	4,510,4	101,39	66,12	902,08
		271	Pulp and Paper Mills	5,557,5	525,7	4,487,3	100,03	64,13	897,46
			Other Paper and Allied	75,7	16,3	23,1	1,36	1,99	4,62
	11		Printing, Publishing	-	21,4	20,7	-	2,61	4,14
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	2,794,5	721,1	90,1	50,30	87,97	18,02
		291	Iron and Steel Mills	400,9	57,2	-	7,21	6,98	-
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	16,8	210,2	101,7	0,30	25,64	20,34
	14		Machinery	51,7	126,9	132,1	0,93	15,48	26,42
	15		Transportation Equipment	18,5	97,1	18,5	0,33	11,84	3,70
	16		Electrical Products	12,4	22,3	11,1	0,22	2,72	2,22
	17		Non-metallic Mineral Pro.	2,720,1	72,1	-	48,96	8,79	-
		352	Cement	635,1	-	-	11,43	-	-
		356	Glass	-	72,1	-	-	8,79	-
			Other Non-metallic	2,085,0	-	-	37,53	-	-
	18		Petroleum and Coal	-	969,5	-	-	118,28	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	962,4	-	-	117,61	-
			Other Petroleum	-	7,1	-	-	0,86	-
	19		Chemical and Chemical Pro.	2,776,9	2,776,9	1,902,7	49,98	339,11	380,54
		378	Industrial Chemicals	2,625,8	2,625,8	1,799,2	47,26	320,35	359,84
			Other Chemicals	151,1	151,1	103,5	2,72	18,43	20,70
7	20		Miscellaneous Manufact.	5,3	5,3	5,3	0,09	0,64	1,06
	04	572	Electric Power: Base Load	30,025,3	-	100,084,4	540,45	-	20,016,8
			Standby	-	-	-	-	-	-
			TOTAL	46,781,0	6,191,0	11,083,0	831,26	755,30	22,166,0

TABLE 7-12

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
BRITISH COLUMBIA - 1976

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	20,4	7,3	-	0,36	0,89	-
4			Mining	3,233,6	497,4	-	58,20	60,68	-
5			Manufacturing Industries	77,766,8	12,977,2	47,304,7	1,399,80	1,583,22	9,500,94
	01		Food and Beverage	665,4	136,3	1,598,1	11,98	19,07	311,62
		101	Meat and Poultry	56,4	56,4	282,1	1,01	6,88	56,42
		104	Dairy	46,4	69,6	185,7	0,83	8,49	37,14
		107	Bakery	13,1	4,3	43,7	0,23	0,52	8,74
		109	Beverage	214,0	10,1	407,6	3,85	1,23	81,52
			Other Food and Beverage	335,5	15,9	639,0	6,04	1,94	127,8
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	8,7	2,5	9,2	0,16	0,30	1,84
	04		Leather	0,6	0,2	0,4	0,01	0,02	0,08
	05		Textiles	7,2	-	-	0,13	-	-
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	9,2	2,0	10,8	0,16	0,24	2,16
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	6,3	7,0	9,1	0,11	0,85	1,82
	08		Wood Products	1,054,3	553,5	395,3	18,97	76,52	79,06
	09		Furniture and Fixtures	12,8	4,0	12,8	0,23	0,48	2,56
	10		Paper and Allied Products	56,409,6	9,065,8	44,926,2	1,016,03	1,106,03	8,985,24
		271	Pulp and Paper Mills	56,295,0	9,047,4	44,835,0	1,013,31	1,103,78	8,967,0
			Other Paper and Allied	114,6	18,4	91,2	2,06	2,24	18,24
	11		Printing, Publishing	-	10,3	10,4	-	1,28	2,08
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	16,334,8	1,675,3	-	294,02	204,38	-
		291	Iron and Steel Mills	256,6	36,6	-	4,61	4,46	-
		295	Smelting and Refining	14,159,0	1,452,2	-	254,86	177,17	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	22,5	282,2	134,3	0,40	34,43	26,86
	14		Machinery	42,4	103,8	108,0	0,76	12,66	21,6
	15		Transportation Equipment	13,9	73,2	13,9	0,25	8,93	2,78
	16		Electrical Products	11,5	20,8	10,2	0,20	2,54	2,04
	17		Non-metallic Mineral Pro.	2,416,3	144,5	-	43,49	17,62	-
		352	Cement	557,4	-	-	10,03	-	-
		356	Glass	-	144,5	-	-	17,62	-
			Other Non-metallic	1,858,9	-	-	33,46	-	-
	18		Petroleum and Coal	-	419,5	-	-	51,18	-
			Products	-	416,7	-	-	50,83	-
		3651	Petroleum Refining	-	2,8	-	-	0,34	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	756,1	453,7	302,4	13,60	55,35	60,48
		378	Industrial Chemicals	704,9	422,9	281,9	12,69	51,59	56,38
			Other Chemicals	51,2	30,8	20,5	0,92	3,76	4,1
7	20		Miscellaneous Manufact.	4,4	4,4	5,6	0,08	0,54	1,2
	04	572	Electric Power; Base Load	83,9	60,4	280,0	1,51	7,36	56,0
			Standby	-	-	-	-	-	-
			TOTAL	81,105,0	13,542,0	47,785,0	1,459,89	1,652,12	9,557,0

TABLE 7-13

POTENTIAL ENERGY RECOVERY BY CHEMICAL HEAT PUMPS
YUKON AND NORTHWEST TERRITORIES - 1978

(Btu x 10^9)

CODE				REJECTED HEAT STREAMS			POTENTIAL HEAT RECOVERY BY CHP		
Div	MC	SIC	INDUSTRY	212°F to 550°F	120°F to 212°F	< 120°F	212°F to 550°F	120°F to 212°F	< 120°F
2	01	031	Logging	-	-	-	-	-	-
4			Mining	114,6	32,7	-	2,0	3,99	-
5			Manufacturing Industries	14,5	56,1	8,0	0,26	6,73	1,6
	01		Food and Beverage	1,7	-	3,3	0,03	-	20,66
		101	Meat and Poultry	-	-	-	-	-	-
		104	Dairy	-	-	-	-	-	-
		107	Bakery	-	-	-	-	-	-
		109	Beverage	-	-	-	-	-	-
			Other Food and Beverage	1,7	-	3,3	0,03	-	0,66
	02		Tobacco	-	-	-	-	-	-
	03		Rubber and Plastics	-	-	-	-	-	-
	04		Leather	-	-	-	-	-	-
	05		Textiles	-	-	-	-	-	-
		183	Man-made Fibres	-	-	-	-	-	-
			Other Textiles	-	-	-	-	-	-
	06		Knitting Mills	-	-	-	-	-	-
	07		Clothing	-	-	-	-	-	-
	08		Wood Products	12,8	8,2	4,0	0,23	1,0	0,8
	09		Furniture and Fixtures	-	-	-	-	-	-
	10		Paper and Allied Products	-	-	-	-	-	-
		271	Pulp and Paper Mills	-	-	-	-	-	-
			Other Paper and Allied	-	-	-	-	-	-
	11		Printing, Publishing	-	0,1	0,1	-	-	0,02
			and Allied Products	-	-	-	-	-	-
	12		Primary Metals	-	-	-	-	-	-
		291	Iron and Steel Mills	-	-	-	-	-	-
		295	Smelting and Refining	-	-	-	-	-	-
			Other Primary Metallic	-	-	-	-	-	-
	13		Metal Fabricating	-	-	-	-	-	-
	14		Machinery	-	-	-	-	-	-
	15		Transportation Equipment	-	-	-	-	-	-
	16		Electrical Products	-	-	-	-	-	-
	17		Non-metallic Mineral Pro.	-	-	-	-	-	-
		352	Cement	-	-	-	-	-	-
		356	Glass	-	-	-	-	-	-
			Other Non-metallic	-	-	-	-	-	-
	18		Petroleum and Coal	-	47,8	-	-	5,83	-
			Products	-	-	-	-	-	-
		3651	Petroleum Refining	-	47,8	-	-	5,83	-
			Other Petroleum	-	-	-	-	-	-
	19		Chemical and Chemical Pro.	-	-	-	-	-	-
		378	Industrial Chemicals	-	-	-	-	-	-
			Other Chemicals	-	-	-	-	-	-
7	20		Miscellaneous Manufact.	-	-	-	-	-	-
	04	572	Electric Power; Base Load	-	339,1	-	-	41,37	-
			Standby	-	-	-	-	-	-
			TOTAL	129,0	428,0	8,0	2,55	51,36	1,6

8 - ESTIMATE OF POTENTIAL FOR ENERGY CONSERVATION IN CANADIAN INDUSTRY

In accordance with the available published data (Reference 21), the distribution of the practical recoverable energy by all means of energy cascading system for various industry rejected heat temperature ranges is summarized below.

Practical Recoverable Energy

Rejected Heat Source	Temperature	As A Percentage of Total Energy Consumption	As A Percentage Of Total Rejected Heat
Furnace & kiln exhaust gases	Higher than 290°C (550°F)	2 percent	48 percent
Boiler exhaust gases	100° - 290°C (212° - 550°F)	3 percent	18 percent
Condensate & process water	50° - 100°C (120° - 212°F)	2 percent	61 percent
Condenser cooling water	Lower than 50°C (120°F)	5 percent	20 percent
Total practical energy to be recovered	50° - 290°C (120° - 550°F)	11 percent	25 percent

Energy recovery by chemical heat pumps provides a very attractive proposition to industry energy users when no other potential uses of waste rejected energy are available or when the rejected heat energy is at such a low temperature that conventional heat exchangers are impractical.

Chemical heat pump applications for rejected heat streams which are higher than 290°C (550°F) are not feasible at present time. In the

100°C - 290°C (212°C to 550°F) rejected heat sources, the potential for CHP is limited due to the high temperature restrictions. It is theoretically possible to utilize CHP to recover waste heat in all rejected heat streams from the 50°C - 100°C (120°F to 212°F) and lower than 50°C (120°F) categories. In practice, industry may find other means of energy cascading systems such as heat exchangers, cogeneration and absorption cooling to be more attractive than CHP in the 50°C - 100°C (120°F - 212°F) category based on technical, economical and other considerations.

For the purposes of this survey it is assumed that the potential for CHP recovery is determined by taking 10 percent of the practical recoverable energy in the 100°C - 290°C (212°F - 550°F) category, 20 percent of the practical recoverable energy in the 50°C - 100°C (120°F to 212°F) category and 100 percent of the practical recoverable energy in the lower than 50°C (120°F) category.

Although electricity or other forms of shaft energy is required to drive the chemical heat pump system circulating pumps, the amount of energy consumed is much less than the energy output of the CHP. Based on data provided by some potential equipment suppliers (Reference 20), it was assumed that approximately 5 percent of the recoverable energy (input to CHP) is required for the utility to generate the equivalent electricity to drive the CHP circulating pumps. It was further assumed that the net energy recovered by all CHP systems is to be 30 percent of the available waste heat stream energy for CHP application.

Table 8-1 summarizes the potential for energy conservation by chemical heat pump applications in Canadian industry with base data provided by Tables 7-1 to 7-13.

A potential for CHP energy recovery exists to some degree in a wide variety of industrial establishments which have process heat energy requirements. The ability to realize this potential in individual establishments depends on the characteristics of the process and the heat requirements, the economic and technical resources available to the

firm, and the availability of a recoverable energy user in a close proximity. The estimates presented in this section indicate the technical potential, but do not include any economic assessments.

TABLE 8-1

CHEMICAL HEAT PUMP POTENTIAL (1978)

10^9 Btu's

Province	Gross Energy Available for CHP Recovery	Additional Energy Req'd At Utility	Net Energy Available for CHP Recovery	Net Energy Recovered By CHP
Newfoundland	1,949	97	1,852	556
Prince Edward Island	383	19	364	109
Nova Scotia	5,482	274	5,208	1,563
New Brunswick	7,792	390	7,402	2,220
Quebec	13,186	659	12,527	3,758
Ontario	106,536	5,327	101,209	30,363
Manitoba	1,722	86	1,636	490
Saskatchewan	8,106	405	7,701	2,310
Alberta	23,752	1,188	22,564	6,769
British Columbia	12,699	635	12,064	3,619
Yukon & NWT	55	3	52	16
Canada	181,622	9,083	172,579	51,773

REFERENCES USED IN CHEMICAL HEAT PUMP STUDY

1. New Development for Thermomechanical Pulping Steam Recovery

Press release by C-E Bauer Company, February 1983
Authors K. A. Meyer, D. W. Hostetter

A falling film heat exchanger for heat recovery from TMP pulping machines is described. It is designed to prevent fouling and corrosion caused by contaminants from the pulping process (fibres, organic acids, complex organics etc.). A pump recirculates TMP condensate to improve heat transfer and to prevent local dry spots where fouling may occur. A 6-8 psi pressure differential between the TMP steam and the clean steam is achieved. Two units of this design are reported to be in service and giving good results. The heat exchanger design is licensed from Rintekno Oy, Finland.

2. Begin-Say Heat Pump Saves Energy

Pulp and Paper Industry, July 1982
P. H. Marchal, J. P. Delaroche

A heat pump has been combined with a TMP refiner to upgrade waste steam so that it may be used in the dryer section of the mill. A falling film heat exchanger is used between the TMP steam and the clean steam. The design temperature difference across the heat exchanger between the TMP steam and the clean steam is 5°C. The refiner steam flow per unit of refiner drive energy is low relative to figures quoted by Ontario Paper and other sources (steam enthalpy is less than 10 percent of the TMP drive energy). The steam is is upgraded to only 2.3 atmospheres relative. (This pressure may be attained directly from a TMP refiner, according to other references). A water ring compressor is used. A power input of 70 kW is required to upgrade 1 ton/h of steam from 2.3 to 3.3 atmospheres absolute. Multiple stage compressors would be required

for higher pressure ratios (4 stages for raising steam from atmospheric to 2.3 atmospheres relative).

3. TMP Steam Recovery for Paper Drying

Transactions, American Pulp and Paper Institute, 1983
K. M. Blumberg

Discusses the energy and mass balance of paper manufacture using the TMP process. Steam with an energy equivalent of 82 percent of the TMP drive energy is available. Pressurised TMP waste steam is used in a falling film heat exchanger to produce clean steam. A thermocompressor is used in the initial energy recovery installation to upgrade this clean steam to 50 psig. Later installations will use mechanical compression, because jet compressors will add additional steam that cannot be used in the mill. The thermocompresors use 2 mass units of high pressure steam for each mass unit of clean TMP derived steam upgraded. Electrical energy used in the TMP refiner is quoted as 0.72 MW·h per oven dried ton of paper produced.

4. Drying Investigations on Large Paper Machines

Papper och Tra, No. 7, 1970

J. Mardon, G. A. Smook, T. W. Stokes, B. J. Howe,
R. E. Monaghan

A three part paper examining the requirements for efficient paper drying. Contains a review of literature on the subject.

5. Heat Recovery in Paper Drying - Practical and Economic Considerations

G. A. Smook

Examines paper machine drying, giving details of economizer (air to air heat exchanger to reclaim heat from the dryer exhaust) operation under different outdoor air conditions.

6. Dryer Hoods and Ventilation - How They Affect Costs and Paper Quality

H. Marshall
Paper Trade Journal, October 1970

The economics of paper drying with varying degrees of hooding over the paper drying machine are discussed. It is claimed that a paper mill in a northern location can hardly stay competitive without a closed hood and an economizer to reclaim heat from the exhaust air stream.

7. Steam Consumption and Dryer Performance on Canadian Newsprint Machines

J. C. Urbas

Pulp and Paper Magazine, Canada, 1972

A survey of the pulp and paper industry shows that steam consumption for paper drying ranges from 1.2 lbs of steam per lb of water removed (5 percent of machines), to 2 lbs of steam per lb (2 percent of machines), with most machines performing in the range of 1.3 to 1.6 lbs/lb. Wet paper entering the machine has a moisture content (moisture as a percentage of fibre plus moisture, wet basis) of 62- to 69 percent, with most mills reporting 67 percent. This is typically dried to 7 percent moisture content, wet basis.

8. Factors Which Affect Steam Consumption in Paper Drying

G. Snook

Paper Trade Journal, April 27, 1970

It is shown that the largest controllable steam usage in paper drying is that for heating the air used to remove the water vapor. Drying hoods reduce the amount of uncontrolled air entering the drying zone, so that a maximum of heat can be recovered in the economizer.

9. Newsprint From TMP Without Fuel Oil

J. Rydquist, L. Lunden, G. Gavelin
Svensk papperstidning, nr 10 1981

Swedish electrical costs are comparable to the cost of fuel oil. The TMP process is being used increasingly, and paper manufacturers are interested in using the waste heat from this process to displace heat from fuel oil. Studies show a good match between the TMP refiner waste heat and steam required for drying, with excess steam available when all the fibre is derived from wood chips:

Refiner steam 3.83 GJ/tonne paper
Paper drying steam 3.36 GJ/tonne paper

An energy balance at the TMP refiner is discussed, and a recovery of 61 percent of the input electrical energy as steam is shown. Most of the balance is recovered as hot or warm water.

Electrical energy, input as shaft or mechanical work, to the TMP is estimated as 1760 kW·h per tonne of paper.

It is considered reasonable to extract steam from a TMP refiner at 2.6 atmospheres (above atmospheric pressure). The temperature drop in the converter would be between 4°C to 10°C. The worst case (10°C) gives clean steam at 1.5 atmospheres. This is considered adequate on a modern paper machine where the drying cylinder steam pressure does not exceed one atmosphere. While it is common practice to distribute drying steam at 3 atmospheres, this is not not mandatory with modern flow control valves and computer control systems.

10. Optimizing Steam Recovery Through the Use of Pressure-Pressure TMP Systems

K. A. Meyer, H. A. Peterson, 1983 TAPPI Conference

This paper contains data showing that TMP refiners can be operated to generate high pressure steam, without significantly affecting the quality of the pulp produced. The data was obtained using a chip feed of spruce and balsam fir, at pressures of 60 psig in the first stage refiner and 50 psig in the second stage refiner.

11. Study on the Recovery of Steam from Thermomechanical Pulping by Vapor Recompression.

N. N. Sayegh, M. K. Azarniouch, S. Prahacs
Pulp and Paper Canada, 1982

Estimates that the recovery of TMP steam can reduce the process energy consumption from 8.2 GJ/oven dried tonne paper to about 4 to 5.5 GJ/tonne. Capital investment would be between $4,400 and $9,000 per (tonne/day TMP capacity). These figures represent recovery from one and two stages of TMP refining respectively. Vapor compression is not necessary when pressurized steam only is to be recovered.

12. Modelling and Simulation of a Heat Recovery System for a Thermomechanical Pulping Plant

M. J. Perkola, P. Vihmari, H. N. Koivo, K. Sannholm, P. Virtanen
Paperi och Tra, No. 11, 1982

A heat recovery system for a TMP process was modelled and a simulator developed. The study indicated that the original design proposal for the system would have been difficult to control. The construction of the system was changed and the problem was overcome. Pressure fluctuations could be eliminated and the controllers were easy to tune.

13. Process Heat Transfer, D. Q. Kern

McGraw-Hill Book Company, 1950.

Approximate heat transfer coefficients, Table 8 of Appendix. Gives ranges for overall heat transfer coefficients that may be expected in a heat exchanger. For example:

water to water, 250 - 500 $Btu/ft^2/h/°F$
steam to water, 200 - 700 $Btu/ft^2/h/°F$

(A falling film heat exchanger would be classified as steam to water and a reasonable estimate of performance would be 500 $Btu/ft^2/h/°F$.)

14. Estimating Costs of Shell-and-Tube Heat Exchangers

G. P. Purohit, Chemical Engineering, August 22, 1983

Summarizes cost experience obtained from numerous heat exchanger purchases. A price of $\$40/ft^2$ is typical for a high alloy steel

heat exchanger, but wide variations can be expected. The author gives complete rules to show how costs vary with design features.

15. Heat Pump Dehumidifier Planned for Cloth Drier at Canada Sandpaper

Energy Management Canada, October 1982

An electrical heat pump is proposed for cloth drying. The heat load is 2.2 M Btu/h for water evaporation, and an additional 7.7 M Btu/h to preheat 35000 cfm of exhausted air. The air temperature used is 250°F. Cost of the installation is estimated at $347,000. Since the drying air is recycled, the 7.7 M Btu/h air preheat load is eliminated.

16. Corrosion Engineering, 2nd Edition, 1977

M. G. Fontana, N. D. Greene

Stress corrosion cracking with hot caustic soda solutions, and corrosion from the strong mineral acids (i.e., sulphuric acid) is described.

17. Chemical Engineers Handbook, 5th edition

Perry, McGraw-Hill Book Company

Section 12, Absorbtion refrigeration
Section 18, Liquid-Gas Systems, absorption tower design
Section 23, Materials of Construction, corrosion and its control

18. Vapour Recompression Study of Ethanol Distillation

Study for Agriculture Canada, by Acres Consulting Services

DSS File Reference 01843-2-EL16

Equipment cost for a falling film heat exchanger estimated at $23 (US)/ft^2 for a 5,000 ft^2 unit.

A 3-stage turbocompressor, 2 atmosphere inlet pressure, 700 kW drive power, is estimated to cost $270/kW.

Costs do not include installation.

19. Dessicant Cooling Arrives

Engineering News Record, May 12, 1983

A dessicant cooling system has been designed for a Washington, DC hospital. It will use lithium chloride as the dessicant. This is preferred over a solid dessicant because it can be regenerated at a lower temperature.

20. Industrial Chemical Heat Pumps: Chemically Driven

By E. Charles Clark, Rocket Research Company

A Division of Rockcor, Inc., Redmond, Washington, 98052, USA

An information package introducing industrial chemical heat pump development and application by Rocket Research Company

21. Energy cascading potential in Canadian Industry

By Lanlonde, Girouard, Letendre and Associates Limited
Publication No. 3a, December 1981.
Energy, Mine and Resources Canada
Conservation and renewable energy research

22. Economic for Upgrading of Waste Heat

By D. C. Erickson, Energy Concept Co.
MD, IECTC, Proceeding, Houston, Texas, 1983

Compare options for upgrading heat energy i.e. mechanical heat pump, thermocompressor and chemical absorption. The mechanical heat pump has an upper temperature limit (330°F). A thermo-compressor has a low second low efficiency (30 percent) and is not suited to a high temperature lift. An absorption heat pump can have a good second law efficiency (80 percent) and can manage a high temperature lift (120°F).

23. Introduction to Hazard and Operability Studies - The Guide word Appraisal

By R. Ellis Knowlton
Chemetics International Ltd.

An outline of a methodology for risk appraisal for process equipment.

APPENDIX 1

THERMODYNAMIC DATA - SULPHURIC ACID

APPENDIX 1

BASIC THERMODYNAMIC DATA -
SULPHURIC ACID

The following expression may be evaluated for vapor pressure over sulphuric acid.

$$\log_{10} P_{(mm)} = A - \frac{B}{T}$$

A and B are functions of concentration, percent H_2SO_4 in the solution

Concentration	A	B
95	9.790	3.888
90	9.255	3.390
85	9.239	3.175
80	9.239	3.040
75	9.034	2.810
70	9.032	2.688
65	8.853	2.533
60	8.841	2.458
55	8.827	2.400
50	8.832	2.351
45	8.809	2.322
40	8.844	2.299
35	8.873	2.286
30	8.864	2.271
20	8.922	2.268
10	8.925	2.259

Source: Perry Chemical Engineers Handbook, 5th Edition, P. 3-64.

Specific heat of H_2SO_4 -3,388 Btu/lbm--Lange's handbook of chemistry, Table 9.1.

TABLE A1-1

PRESSURE (Kpa)

	Concentration Percent Acid													
Temp(°C)	74	72	70	68	66	64	62	60	58	56	54	52	50	48
60	0.54	0.81	1.22	1.57	2.03	2.62	3.38	3.84	4.47	5.19	6.04	7.02	7.57	8.32
65	0.72	1.07	1.60	2.06	2.64	3.39	4.36	4.94	5.73	6.65	7.71	8.94	9.63	10.58
70	0.96	1.41	2.09	2.67	3.41	4.36	5.58	6.31	7.30	8.44	9.77	11.31	12.17	13.35
75	1.26	1.84	2.71	3.45	4.38	5.57	7.09	7.99	9.23	10.66	12.31	14.21	15.27	16.73
80	1.64	2.39	3.48	4.41	5.58	7.07	8.94	10.06	11.60	13.36	15.40	17.74	19.05	20.85
85	2.13	3.08	4.45	5.61	7.07	8.90	11.22	12.59	14.48	16.65	19.15	22.02	23.61	25.81
90	2.74	3.93	5.65	7.08	8.89	11.14	13.98	15.65	17.96	20.62	23.66	27.16	29.09	31.77
95	3.49	4.99	7.12	8.89	11.10	13.86	17.31	19.34	22.16	25.38	29.08	33.31	35.65	38.88
100	4.44	6.29	8.92	11.09	13.79	17.15	21.32	23.77	27.18	31.08	35.53	40.62	43.44	47.32
105	5.60	7.89	11.11	13.76	17.03	21.09	26.11	29.06	33.16	37.85	43.19	49.29	52.66	57.31
110	7.02	9.83	13.76	16.97	20.92	25.80	31.82	35.33	40.25	45.85	52.23	59.51	63.51	69.05
115	8.75	12.17	16.95	20.81	25.56	31.40	38.57	42.74	48.61	55.28	62.86	71.49	76.24	82.80
120	10.84	15.00	20.76	25.40	31.08	38.02	46.52	51.46	58.42	66.32	75.30	85.49	91.09	98.84
125	13.37	18.39	25.30	30.84	37.59	45.82	55.85	61.66	69.89	79.22	89.78	101.76	108.34	117.45
130	16.40	22.43	30.69	37.27	45.26	54.96	66.75	73.56	83.24	94.20	106.59	120.62	128.31	138.97
135	20.01	27.22	37.04	44.82	54.24	65.64	79.43	87.38	98.72	111.54	126.02	142.38	151.34	163.76
140	24.30	32.89	44.51	53.67	64.72	78.05	94.12	103.35	116.59	131.53	148.38	167.38	177.78	192.20
145	29.38	39.55	53.25	63.99	76.90	92.42	111.07	121.76	137.16	154.49	174.02	196.02	208.04	224.72
150	35.35	47.46	63.43	75.98	91.00	109.01	130.57	142.90	160.73	180.78	203.33	228.70	242.55	261.78
155	42.36	56.46	75.25	89.85	107.27	128.07	152.91	167.08	187.65	210.76	236.72	265.87	281.77	303.86
160	50.55	67.05	88.93	105.84	125.96	149.91	178.42	194.64	218.31	244.85	274.62	308.01	326.20	351.49
165	60.08	79.31	104.69	124.21	147.37	174.85	207.45	225.96	253.09	283.48	317.51	355.63	376.38	405.25
170	71.13	93.46	122.80	145.25	171.81	203.22	240.38	261.44	292.44	327.11	365.90	409.29	432.87	465.72
175	83.89	109.72	143.52	169.26	199.61	235.41	277.64	301.51	336.82	376.27	420.33	469.56	496.30	533.56
180	98.58	128.37	167.16	196.57	231.15	271.82	319.64	346.62	386.72	431.47	481.39	537.08	567.30	609.44
185	115.43	149.66	194.05	227.54	266.82	312.87	366.87	397.28	442.69	493.29	549.68	612.51	646.57	694.10
190	134.71	173.92	224.54	262.56	307.03	359.03	419.83	453.99	505.27	562.34	625.86	696.55	734.86	788.31
195	156.69	201.45	259.01	302.05	352.25	410.79	479.05	517.33	575.08	639.27	710.63	789.95	832.87	892.87
200	181.67	232.62	297.87	346.45	402.95	468.67	545.10	587.88	652.74	724.75	804.71	893.49	941.49	1008.63
205	209.98	267.81	341.56	396.24	459.66	533.24	618.59	666.26	738.92	819.51	908.89	1008.01	1061.55	1136.51
210	241.98	307.42	390.56	451.92	522.92	605.08	700.15	753.14	834.34	924.30	1023.96	1134.36	1193.95	1277.43
215	278.05	351.90	445.36	514.04	593.32	686.83	790.45	849.22	939.75	1039.93	1150.79	1273.47	1339.63	1432.40
220	318.60	401.70	506.49	583.18	671.47	773.14	890.20	955.22	1055.91	1167.23	1290.27	1426.29	1499.58	1602.44
225	364.06	457.34	574.53	659.94	758.04	870.72	1000.15	1071.92	1183.67	1307.07	1443.34	1595.81	1674.83	1788.63
230	414.90	519.35	650.08	744.96	853.70	978.30	1121.09	1200.12	1323.87	1460.38	1610.97	1777.09	1866.46	1992.09
235	471.63	588.28	733.78	838.94	959.18	1096.65	1253.83	1340.67	1477.42	1628.11	1794.18	1977.19	2075.58	2214.00
240	534.78	664.75	826.30	942.59	1075.26	1226.59	1399.22	1494.45	1645.25	1811.27	1994.04	2195.26	2303.36	2455.57
245	604.92	749.39	928.16	1056.67	1202.72	1368.96	1558.18	1662.38	1828.35	2010.89	2211.65	2432.46	2551.00	2718.06
250	682.65	842.87	1040.70	1181.97	1342.42	1524.65	1731.62	1845.42	2027.73	2228.05	2448.16	2690.01	2819.76	3002.77
255	768.60	945.90	1164.11	1319.32	1495.23	1694.59	1920.54	2044.56	2244.45	2463.87	2704.74	2969.17	3110.92	3311.05
260	863.45	1059.24	1299.43	1469.60	1662.07	1879.74	2125.92	2260.85	2479.60	2719.51	2982.64	3271.22	3425.82	3644.29
265	967.90	1185.66	1447.51	1633.72	1843.90	2081.11	2348.83	2495.34	2734.32	2996.17	3283.11	3597.52	3765.85	4003.93
270	1082.72	1319.99	1609.26	1812.63	2041.71	2299.75	2590.35	2749.16	3009.78	3295.10	3607.47	3949.45	4132.41	4391.44
275	1208.68	1469.11	1785.64	2007.33	2256.54	2536.68	2851.61	3023.45	3307.19	3617.56	3957.07	4328.43	4526.98	4808.34
280	1346.61	1631.90	1977.63	2218.83	2489.46	2793.10	3133.77	3319.38	3627.81	3964.89	4333.29	4735.92	4951.05	5256.19
285	1497.38	1809.32	2186.25	2448.23	2741.60	3070.13	3438.03	3638.19	3972.91	4338.42	4737.56	5173.42	5406.17	5736.60
290	1661.90	2002.36	2412.58	2696.62	3014.11	3368.98	3765.63	3981.13	4343.83	4739.56	5171.35	5642.48	5893.90	6251.19
295	1841.11	2212.05	2657.72	2965.17	3308.18	3690.87	4117.84	4349.50	4741.92	5169.74	5636.16	6144.67	6415.87	6801.65
300	2036.00	2439.44	2922.83	3255.06	3625.05	4037.09	4495.97	4744.61	5168.57	5630.42	6133.53	6681.60	6973.74	7389.69
305	2247.60	2685.67	3209.11	3567.53	3965.98	4408.96	4901.36	5167.83	5625.22	6123.09	6665.03	7254.93	7569.18	8017.05
310	2477.00	2951.87	3517.78	3903.86	4332.30	4807.76	5335.41	5620.57	6113.34	6649.31	7232.27	7866.34	8203.93	8685.54

TABLE A1-2

PRESSURE (Psia)

Temp (°F)	Concentration Percent Acid													
	74	72	70	68	66	64	62	60	58	56	54	52	50	48
180	0.27	0.39	0.56	0.71	0.90	1.14	1.44	1.61	1.86	2.14	2.46	2.83	3.04	3.33
185	0.31	0.45	0.65	0.81	1.02	1.29	1.63	1.83	2.10	2.41	2.78	3.19	3.42	3.74
190	0.35	0.51	0.74	0.93	1.16	1.46	1.84	2.06	2.37	2.72	3.13	3.59	3.85	4.20
195	0.41	0.59	0.86	1.05	1.32	1.66	2.08	2.32	2.67	3.06	3.51	4.03	4.32	4.71
200	0.47	0.67	0.96	1.20	1.50	1.87	2.34	2.62	3.00	3.44	3.94	4.52	4.83	5.27
205	0.53	0.76	1.09	1.36	1.69	2.11	2.63	2.94	3.36	3.85	4.41	5.05	5.40	5.89
210	0.61	0.87	1.23	1.53	1.91	2.37	2.95	3.30	3.77	4.31	4.93	5.64	6.03	6.57
215	0.70	0.98	1.39	1.73	2.15	2.67	3.31	3.69	4.21	4.82	5.50	6.29	6.72	7.32
220	0.79	1.12	1.57	1.95	2.41	2.99	3.70	4.12	4.71	5.37	6.13	7.00	7.48	8.14
225	0.90	1.26	1.77	2.19	2.71	3.35	4.14	4.60	5.25	5.98	6.82	7.78	8.31	9.04
230	1.02	1.43	2.00	2.46	3.03	3.74	4.61	5.12	5.84	6.65	7.58	8.63	9.21	10.02
235	1.15	1.61	2.24	2.76	3.39	4.18	5.14	5.70	6.49	7.38	8.40	9.56	10.20	11.08
240	1.30	1.81	2.51	3.09	3.79	4.65	5.71	6.33	7.20	8.18	9.30	10.58	11.28	12.25
245	1.46	2.03	2.82	3.45	4.23	5.18	6.34	7.02	7.97	9.06	10.29	11.69	12.46	13.52
250	1.65	2.28	3.15	3.85	4.70	5.75	7.03	7.77	8.82	10.01	11.36	12.89	13.74	14.90
255	1.85	2.55	3.51	4.29	5.23	6.38	7.78	8.59	9.74	11.05	12.53	14.20	15.12	16.40
260	2.08	2.85	3.92	4.77	5.80	7.06	8.60	9.49	10.75	12.18	13.80	15.63	16.63	18.03
265	2.33	3.18	4.36	5.29	6.43	7.81	9.49	10.46	11.84	13.40	15.17	17.17	18.27	19.79
270	2.60	3.55	4.84	5.87	7.12	8.63	10.46	11.52	13.03	14.74	16.66	18.84	20.04	21.69
275	2.90	3.95	5.37	6.50	7.87	9.52	11.52	12.67	14.32	16.18	18.28	20.65	21.95	23.75
280	3.23	4.39	5.95	7.19	8.68	10.49	12.67	13.92	15.71	17.74	20.02	22.60	24.02	25.97
285	3.60	4.87	6.59	7.94	9.57	11.54	13.91	15.27	17.22	19.42	21.91	24.71	26.24	28.37
290	4.00	5.40	7.28	8.76	10.54	12.68	15.25	16.73	18.85	21.25	23.94	26.98	28.65	30.95
295	4.44	5.97	8.03	9.65	11.58	13.91	16.70	18.31	20.61	23.21	26.14	29.43	31.23	33.73
300	4.92	6.60	8.85	10.61	12.72	15.25	18.27	20.01	22.51	25.33	28.50	32.06	34.01	36.71
305	5.45	7.29	9.74	11.66	13.95	16.69	19.97	21.84	24.56	27.61	31.04	34.89	37.00	39.92
310	6.02	8.03	10.71	12.79	15.28	18.25	21.80	23.82	26.76	30.06	33.76	37.93	40.20	43.35
315	6.65	8.84	11.76	14.02	16.72	19.93	23.76	25.95	29.12	32.69	36.69	41.18	43.63	47.04
320	7.33	9.72	12.90	15.35	18.27	21.74	25.88	28.23	31.66	35.51	39.83	44.67	47.31	50.98
325	8.07	10.68	14.13	16.79	19.94	23.69	28.15	30.68	34.39	38.54	43.19	48.41	51.25	55.20
330	8.88	11.72	15.46	18.33	21.75	25.79	30.59	33.31	37.31	41.78	46.79	52.40	55.45	59.70
335	9.76	12.84	16.89	20.00	23.69	28.04	33.21	36.13	40.43	45.25	50.64	56.67	59.94	64.51
340	10.70	14.05	18.44	21.80	25.77	30.46	36.01	39.15	43.78	48.96	54.75	61.22	64.74	69.64
345	11.73	15.36	20.11	23.74	28.01	33.06	39.01	42.38	47.35	52.92	59.13	66.07	69.85	75.10
350	12.84	16.78	21.91	25.81	30.41	35.81	42.22	45.83	51.17	57.14	63.80	71.25	75.29	80.92
355	14.05	18.30	23.84	28.04	32.99	38.81	45.65	49.51	55.24	61.64	68.79	76.75	81.08	87.11
360	15.34	19.94	25.92	30.44	35.75	41.98	49.31	53.43	59.58	66.44	74.09	82.61	87.24	93.69
365	16.74	21.71	28.14	33.00	38.70	45.38	53.21	57.62	64.21	71.55	79.72	88.84	93.78	100.67
370	18.25	23.61	30.53	35.75	41.85	49.00	57.37	62.08	69.13	76.97	85.71	95.45	100.72	108.08
375	19.87	25.64	33.09	38.68	45.22	52.87	61.80	66.82	74.35	82.74	92.08	102.46	108.09	115.94
380	21.62	27.83	35.83	41.82	48.82	56.98	66.51	71.86	79.91	88.87	98.82	109.90	115.89	124.27
385	23.49	30.18	38.76	45.18	52.65	61.37	71.52	77.21	85.81	95.36	105.98	117.78	124.16	133.09
390	25.50	32.69	41.89	48.75	56.74	66.03	76.84	82.90	92.07	102.25	113.56	126.12	132.91	142.41
395	27.66	35.37	45.23	52.57	61.08	70.98	82.49	88.92	98.70	109.54	121.58	134.94	142.17	152.27
400	29.97	38.25	48.80	56.63	65.71	76.25	88.48	95.31	105.72	117.26	130.07	144.27	151.94	162.68
405	32.45	41.31	52.60	60.95	70.62	81.84	94.83	102.08	113.15	125.43	139.04	154.12	162.27	173.68
410	35.10	44.59	56.65	65.55	75.84	87.76	101.55	109.23	121.01	134.06	148.51	164.53	173.17	185.28
415	37.93	48.08	60.95	70.43	81.38	94.04	108.66	116.80	129.32	143.17	158.51	175.50	184.66	197.50
420	40.95	51.80	65.53	75.62	87.26	100.69	116.18	124.80	138.09	152.79	169.06	187.06	196.77	210.38
425	44.17	55.76	70.40	81.12	93.48	107.72	124.13	133.25	147.35	162.94	180.18	199.25	209.52	223.94
430	47.61	59.98	75.56	86.96	100.07	115.16	132.52	142.17	157.12	173.64	191.90	212.08	222.95	238.21

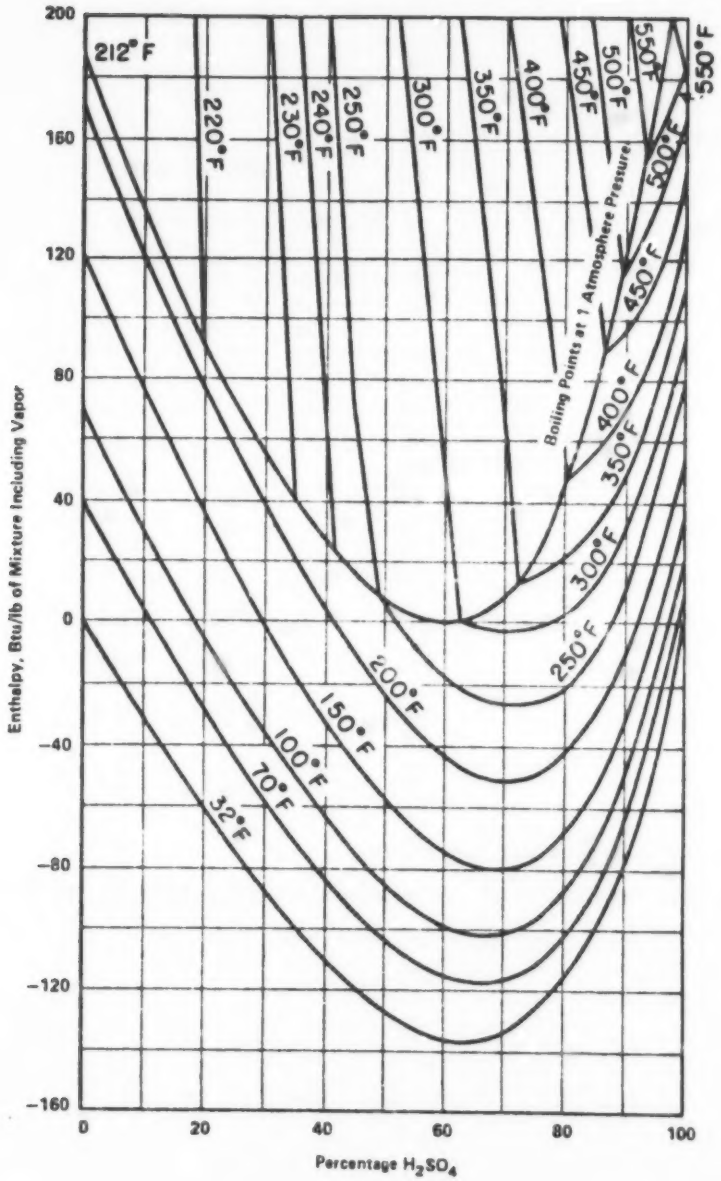
TABLE A1-3

INCREMENTAL BOND ENTHALPY

Concentration	Latent Heat of Vaporization H_{fg}	$h/_m$ Incremental Bond Enthalpy
0	1,025.0[1]	
30	1,033.2[2]	8.2
20	1,036.8	11.8
30	1,038.6	13.6
40	1,051.2	26.2
45	1,062.0	31.0
50	1,076.4	51.4
55	1,096.2	71.2
60	1,123.2	98.2
65	1,157.4	132.4
70	1,227.6	202.6
75	1,283.4	258.4
80	1,389.6	364.6
85	1,450.8	425.8
90	1,549.8	524.8
95	1,776.6	751.6

[1] Latent heat of evaopration at atmospheric pressure, 120°F subtract this value from following figures in this column to obtain incremental bond enthalpy.

[2] This and following figures from Tables 3 to 13, Perry Chemical Engineers Handbook, Fifth Edition.



NOTE:

Enthalpy-concentration diagram for aqueous sulphuric acid at 1 atmosphere. Reference states: Enthalpies of pure liquid components at 32°F, and vapor pressures are zero.

Figure A1-1

THERMODYNAMIC DATA
SULPHURIC ACID

ACRES

TABLE A1-4

PARTIAL PRESSURE OF H_2SO_4 AND H_2O OVER SULPHURIC ACID SOLUTIONS

89.25 percent H_2SO_4			91.26 percent H_2SO_4		
Temperature °C	$P_{H_2SO_4}$	P_{H_2O}	Temperature °C	$P_{H_2SO_4}$	P_{H_2O}
183	.5	78.8	191	.6	50.7
197	1.3	116.9	205	1.9	84.1
216	2.1	233.1	222	4.5	158.5
230	3.6	306.3	242	6.4	271.6
241	5.3	414.8	252	11.3	385.3
			258	13.6	448.7
			262	16.3	411.1

NOTES: 1. Pressures are in mm Hg.

2. At higher acid concentration, the partial pressure of H_2SO_4 becomes increasingly dominant.

APPENDIX 2

THERMODYNAMIC DATA - CAUSTIC ACID

APPENDIX 2

THERMODYNAMIC DATA - CAUSTIC SODA

Vapor pressure over caustic soda is tabulated (Perry, Chemical Engineers Handbook, 5th edition, Pages 3 to 69). This table is used to evaluate A and B in the expression

$$\log_{10} P_{(mm)} = A - \frac{B}{T}$$

Using values at 100°C and 200°C, the following values are obtained.

	Concentration, Grams N_aOH/100 grams H_2O												
A	0	10	20	30	40	50	60	70	80	90	100	110	120
B	2,091	2,092	2,114	2,156	2,219	2,300	2,401	2,508	2,624	2,751	2,879	3,135	3,394

Specific heat - Lange's handbook, Table 9.1 .5 Btu/lbm N_aOH (liquid).

TABLE A2-1

SI UNITS

PRESSURE (kPa)

Temp (°C)	Concentration grams NaOH/100g H2O												
	160	150	140	130	120	110	100	90	80	70	60	50	40
60	0.18	0.27	0.38	0.55	0.80	1.16	1.66	2.36	3.43	4.82	6.68	8.87	11.51
65	0.26	0.38	0.54	0.77	1.10	1.58	2.22	3.13	4.48	6.23	8.54	11.22	14.45
70	0.38	0.54	0.76	1.06	1.50	2.13	2.96	4.12	5.82	8.00	10.84	14.10	18.01
75	0.54	0.76	1.05	1.45	2.02	2.85	3.91	5.37	7.49	10.19	13.66	17.61	22.31
80	0.76	1.06	1.45	1.98	2.72	3.77	5.12	6.95	9.58	12.89	17.11	21.84	27.47
85	1.06	1.46	1.97	2.66	3.61	4.96	6.65	8.92	12.17	16.19	21.29	26.94	33.62
90	1.46	1.99	2.66	3.55	4.77	6.47	8.59	11.39	15.36	20.22	26.34	33.02	40.92
95	2.00	2.70	3.57	4.71	6.25	8.39	11.00	14.43	19.25	25.10	32.39	40.26	49.55
100	2.72	3.62	4.74	6.19	8.13	10.80	14.01	18.18	23.99	30.98	39.62	48.83	59.68
105	3.67	4.83	6.25	8.08	10.50	13.80	17.72	22.76	29.72	38.02	48.20	58.92	71.54
110	4.91	6.40	8.19	10.47	13.47	17.53	22.28	28.32	36.62	46.41	58.34	70.74	85.34
115	6.52	8.41	10.65	13.49	17.18	22.13	27.85	35.05	44.88	56.36	70.27	84.54	101.35
120	8.60	10.97	13.76	17.26	21.77	27.77	34.61	43.14	54.71	68.11	84.23	100.57	119.84
125	11.26	14.23	17.67	21.95	27.42	34.64	42.78	52.83	66.36	81.92	100.52	119.13	141.10
130	14.64	18.32	22.55	27.74	34.34	42.99	52.60	64.36	80.12	98.08	119.42	140.51	165.46
135	18.91	23.46	28.59	34.87	42.76	53.06	64.35	78.03	96.28	116.91	141.29	165.06	193.28
140	24.29	29.85	36.06	43.58	52.98	65.17	78.34	94.16	115.18	138.76	166.47	193.15	224.92
145	31.00	37.77	45.22	54.19	65.30	79.64	94.92	113.13	137.21	164.02	195.38	225.17	260.79
150	39.34	47.52	56.40	67.02	80.09	96.86	114.49	135.32	162.78	193.12	228.44	261.55	301.33
155	49.64	59.46	69.98	82.49	97.75	117.27	137.49	161.19	192.34	226.51	266.13	302.74	347.00
160	62.31	74.03	86.41	101.04	118.77	141.36	164.42	191.23	226.39	264.70	308.94	349.24	398.28
165	77.81	91.70	106.18	123.19	143.67	169.67	195.81	225.99	265.48	308.23	357.41	401.57	455.72
170	96.67	113.05	129.87	149.52	173.04	202.81	232.29	266.06	310.21	357.69	412.13	460.29	519.85
175	119.53	138.72	158.13	180.70	207.56	241.46	274.51	312.09	361.21	413.70	473.73	525.99	591.26
180	147.11	169.45	191.70	217.47	247.96	286.37	323.22	364.80	419.19	476.96	542.85	599.30	670.58
185	180.23	206.08	231.43	260.67	295.07	338.38	379.21	424.97	484.89	548.18	620.22	680.88	758.45
190	219.83	249.57	278.26	311.22	349.82	398.39	443.36	493.42	559.14	628.14	706.58	771.44	855.55
195	267.01	301.01	333.25	370.18	413.22	467.40	516.65	571.08	642.79	717.68	802.72	871.71	962.61
200	322.98	361.61	397.58	438.69	486.40	546.52	600.10	658.93	736.78	817.67	909.48	982.48	1080.37
205	389.13	432.76	472.59	518.04	570.59	636.95	694.85	758.01	842.10	929.06	1027.76	1104.56	1209.61
210	467.02	515.97	559.74	609.63	667.15	740.00	802.12	869.46	959.82	1052.83	1158.48	1238.79	1351.14
215	558.41	612.98	660.67	715.04	777.54	857.07	923.24	994.51	1091.07	1190.03	1302.63	1386.08	1505.82
220	665.27	725.68	777.18	835.96	903.39	989.72	1059.61	1134.44	1237.05	1341.78	1461.24	1547.35	1674.52
225	789.79	856.20	911.26	974.27	1046.46	1139.60	1212.77	1290.65	1399.03	1509.24	1635.38	1723.57	1858.15
230	934.44	1006.87	1065.10	1132.01	1208.65	1308.50	1384.35	1464.60	1578.35	1693.64	1826.18	1915.75	2057.66
235	1101.91	1180.29	1241.08	1311.41	1392.01	1498.35	1576.09	1657.87	1776.44	1896.25	2034.82	2124.93	2274.02
240	1295.24	1379.30	1441.85	1514.89	1598.79	1711.22	1789.86	1872.11	1994.78	2118.43	2262.52	2352.19	2508.23
245	1517.74	1607.03	1670.24	1745.08	1831.39	1949.33	2027.63	2109.08	2234.94	2361.59	2510.55	2598.66	2761.34
250	1773.08	1866.89	1929.39	2004.81	2092.38	2215.04	2291.52	2370.64	2498.59	2627.20	2780.24	2865.49	3034.41
255	2065.28	2162.62	2222.66	2297.16	2384.54	2510.89	2583.76	2658.74	2787.45	2916.78	3072.95	3153.87	3328.53
260	2398.77	2498.29	2553.72	2625.43	2710.83	2839.57	2906.72	2975.45	3103.32	3231.94	3390.11	3465.03	3644.83
265	2778.36	2878.34	2926.53	2993.16	3074.44	3203.94	3262.89	3322.93	3448.10	3574.32	3733.18	3800.24	3984.45
270	3209.33	3307.56	3345.36	3404.18	3478.75	3607.04	3654.92	3703.44	3823.76	3945.66	4103.67	4160.79	4348.58
275	3697.40	3791.16	3814.81	3862.55	3927.36	4052.07	4085.58	4119.37	4232.36	4347.72	4503.15	4548.03	4738.42
280	4248.81	4334.76	4339.82	4372.65	4424.11	4542.46	4557.80	4573.20	4676.02	4782.35	4933.23	4963.31	5155.20

TABLE A2-2

IMPERIAL UNITS

	PRESSURE (Psia) Concentration grams NaOH/100g H2O												
Temp (°F)	160	150	140	130	120	110	100	90	80	70	60	50	40
200	0.26	0.35	0.47	0.62	0.83	1.12	1.47	1.94	2.59	3.39	4.39	5.47	6.75
205	0.31	0.42	0.55	0.73	0.96	1.29	1.68	2.20	2.93	3.82	4.92	6.10	7.49
210	0.37	0.49	0.65	0.85	1.11	1.48	1.93	2.51	3.32	4.29	5.50	6.79	8.31
215	0.44	0.58	0.75	0.98	1.29	1.70	2.20	2.84	3.74	4.81	6.14	7.54	9.20
220	0.52	0.68	0.88	1.14	1.48	1.95	2.50	3.22	4.21	5.39	6.84	8.37	10.17
225	0.61	0.79	1.02	1.32	1.70	2.23	2.85	3.64	4.73	6.03	7.61	9.27	11.23
230	0.71	0.93	1.19	1.52	1.95	2.54	3.23	4.11	5.31	6.73	8.46	10.26	12.38
235	0.83	1.08	1.38	1.75	2.24	2.90	3.66	4.63	5.95	7.50	9.39	11.33	13.63
240	0.98	1.26	1.59	2.01	2.56	3.29	4.14	5.20	6.66	8.35	10.40	12.50	14.98
245	1.14	1.46	1.83	2.31	2.92	3.74	4.67	5.84	7.43	9.28	11.51	13.77	16.44
250	1.32	1.69	2.11	2.64	3.32	4.23	5.26	6.55	8.29	10.30	12.71	15.15	18.03
255	1.54	1.95	2.43	3.02	3.78	4.79	5.92	7.33	9.22	11.41	14.02	16.65	19.74
260	1.78	2.25	2.78	3.44	4.29	5.40	6.65	8.19	10.25	12.62	15.45	18.26	21.59
265	2.06	2.58	3.18	3.92	4.86	6.09	7.46	9.13	11.38	13.95	17.00	20.01	23.58
270	2.38	2.97	3.64	4.46	5.49	6.85	8.35	10.17	12.62	15.39	18.67	21.90	25.73
275	2.74	3.40	4.15	5.06	6.20	7.70	9.33	11.32	13.96	16.96	20.49	23.94	28.03
280	3.15	3.89	4.72	5.73	6.99	8.63	10.42	12.57	15.43	18.66	22.46	26.14	30.51
285	3.62	4.45	5.36	6.48	7.87	9.67	11.61	13.94	17.04	20.51	24.58	28.50	33.17
290	4.15	5.07	6.09	7.31	8.84	10.81	12.92	15.44	18.78	22.51	26.88	31.04	36.02
295	4.74	5.77	6.89	8.24	9.91	12.07	14.36	17.08	20.68	24.68	29.35	33.77	39.07
300	5.41	6.55	7.79	9.28	11.10	13.46	15.93	18.87	22.74	27.02	32.01	36.70	42.34
305	6.17	7.43	8.79	10.42	12.42	14.98	17.66	20.81	24.97	29.55	34.88	39.84	45.83
310	7.02	8.41	9.91	11.69	13.87	16.66	19.54	22.93	27.39	32.28	37.96	43.21	49.55
315	7.97	9.51	11.15	13.10	15.47	18.49	21.60	25.24	30.01	35.22	41.26	46.81	53.53
320	9.04	10.74	12.53	14.65	17.23	20.50	23.85	27.74	32.84	38.39	44.81	50.65	57.77
325	10.23	12.10	14.06	16.37	19.16	22.70	26.29	30.45	35.89	41.80	48.61	54.76	62.28
330	11.56	13.62	15.75	18.26	21.28	25.11	28.95	33.38	39.18	45.46	52.67	59.14	67.08
335	13.05	15.30	17.62	20.34	23.60	27.73	31.84	36.56	42.73	49.39	57.02	63.81	72.18
340	14.70	17.17	19.69	22.63	26.14	30.59	34.98	39.99	46.55	53.60	61.67	68.79	77.60
345	16.55	19.23	21.96	25.14	28.92	33.70	38.38	43.70	50.66	58.11	66.63	74.08	83.36
350	18.59	21.52	24.47	27.89	31.96	37.09	42.06	47.70	55.07	62.94	71.92	79.70	89.46
355	20.85	24.04	27.22	30.91	35.27	40.76	46.04	52.01	59.81	68.10	77.56	85.68	95.92
360	23.36	26.82	30.25	34.20	38.87	44.75	50.35	56.65	64.89	73.62	83.57	92.03	102.76
365	26.14	29.89	33.57	37.81	42.80	49.08	55.00	61.64	70.33	79.51	89.96	98.75	110.00
370	29.21	33.26	37.20	41.74	47.06	53.76	60.01	67.00	76.15	85.79	96.75	105.88	117.66
375	32.59	36.97	41.18	46.03	51.69	58.83	65.42	72.75	82.37	92.48	103.96	113.43	125.74
380	36.31	41.03	45.53	50.69	56.72	64.30	71.23	78.92	89.02	99.60	111.61	121.42	134.27
385	40.41	45.49	50.28	55.77	62.16	70.21	77.49	85.53	96.12	107.18	119.73	129.87	143.27
390	44.92	50.37	55.46	61.29	68.06	76.58	84.21	92.60	103.69	115.23	128.33	138.79	152.76
395	49.87	55.71	61.11	67.28	74.43	83.45	91.43	100.17	111.76	123.79	137.44	148.21	162.75
400	55.29	61.54	67.25	73.77	81.32	90.84	99.17	108.26	120.35	132.87	147.07	158.15	173.27
405	61.23	67.90	73.93	80.81	88.75	98.79	107.46	116.89	129.49	142.50	157.26	168.63	184.33
410	67.74	74.84	81.18	88.42	96.76	107.33	116.34	126.11	139.21	152.70	168.02	179.67	195.97
415	74.84	82.39	89.05	96.65	105.39	116.50	125.84	135.93	149.53	163.50	179.39	191.30	208.19
420	82.60	90.60	97.58	105.54	114.69	126.33	135.99	146.39	160.49	174.94	191.38	203.53	221.02
425	91.05	99.53	106.82	115.13	124.68	136.87	146.83	157.52	172.11	187.03	204.02	216.39	234.48
430	100.27	109.22	116.81	125.48	135.41	148.15	158.40	169.36	184.43	199.80	217.35	229.91	248.59
435	110.30	119.73	127.61	136.62	146.94	160.23	170.74	181.94	197.48	213.29	231.38	244.11	263.39
440	121.20	131.12	139.27	148.60	159.30	173.13	183.88	195.31	211.29	227.53	246.14	259.01	278.88
445	133.04	143.45	151.85	161.49	172.54	186.91	197.88	209.48	225.90	242.54	261.67	274.64	295.10
450	145.89	156.78	165.41	175.34	186.72	201.63	212.77	224.52	241.34	258.36	277.98	291.03	312.07

TABLE A2-3

INCREMENTAL BOND ENTHALPY

Concentration[1]	H Per[2] 1 lbm Mixture	H Per[3] 1 lbm N_aOH	lbm H_2O[4] per 1 lbm N_aOH	H/ m[5] Incremental Bond Enthalpy
.05	25	500	19.0	
.10	50	500	9.0	3
.15	73	486	5.67	20
.20	86	430	4	30
.25	100	400	3	50
.30	105	350	2.33	60
.35	110	314	1.85	80
.40	115	287	1.5	150
.45	105	233	1.22	190
.50	90	180	1.0	210
.55	85	154	.818	240
.60	75	125	.67	260
.65	57	88	.538	300
.70	34	48	.43	310
.75	13	17	.33	

[1] PU weight N_aOH in mixture.

[2] Source - Figure 3.40, Perry, Chemical Engineers Handbook. Normalizing line drawn from zero concentration, 300°F (268 Btu/lb) to 100 percent N_aOH, 300°F (T x Cp + H solution i.e., 268 x .5 + 463 = 597 Btu/lb).

[3] Column 2/Column 1.

[4] (1- Column 3/Column 1).

[5] Estimated from H in Column 3 and m in Column 5.

Column 5 is the incremental bond enthalpy that must be accounted for when water or watervapor is added to a solution of NaOH at a particular concentration.

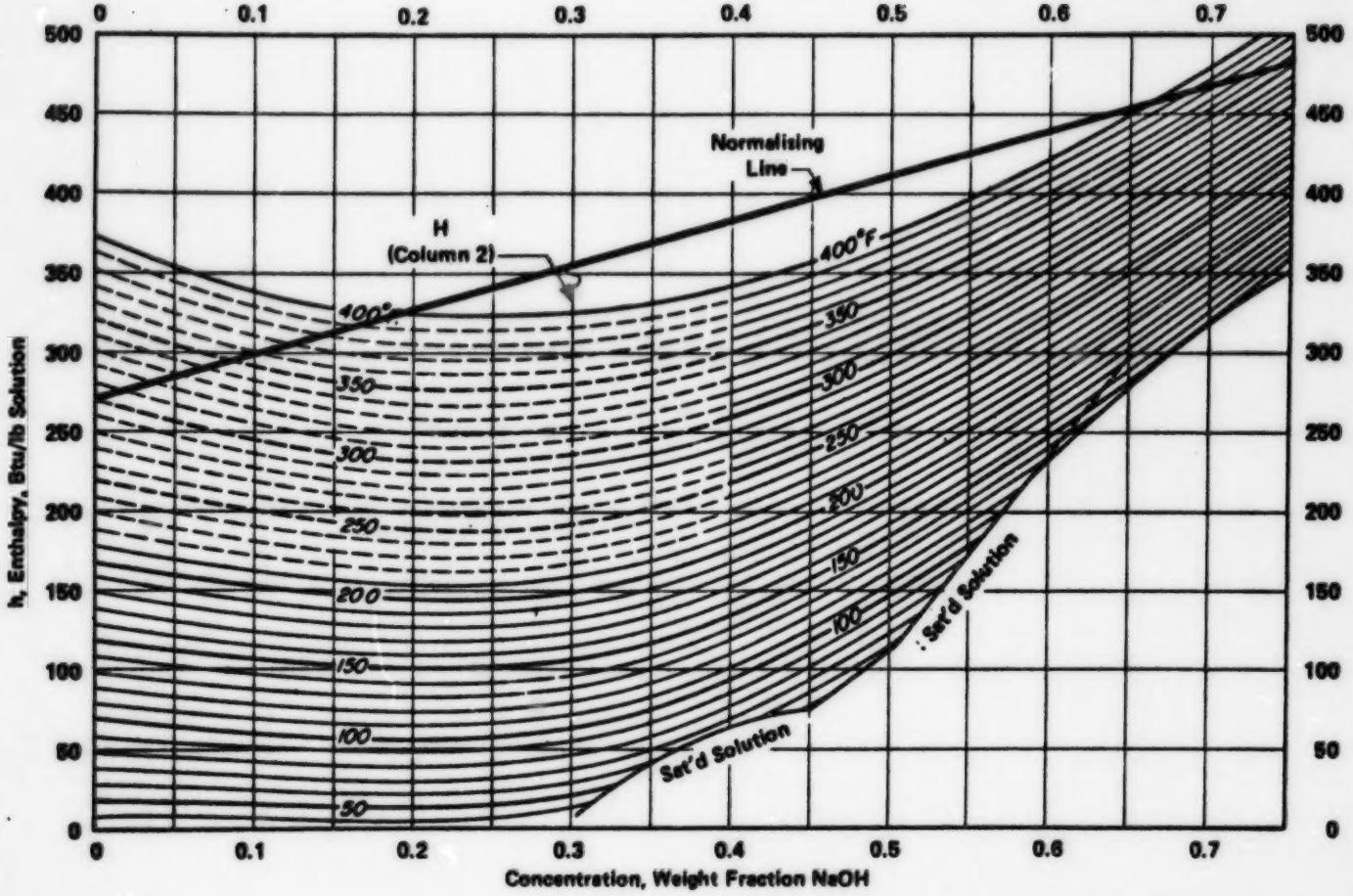


Figure A2-1

THERMODYNAMIC DATA
CAUSTIC SODA

NOTE:

Enthalphy-concentration diagram for aqueous sodium hydroxide at 1 atmosphere.
Normalizing line to set enthalpies of pure liquid components to zero at 300°F.

APPENDIX 3

HEAT BALANCE - SULPHURIC ACID HEAT PUMP

APPENDIX 3

CHEMICAL HEAT PUMP - STEAM QUALITY UPGRADING USING HIGH QUALITY STEAM - SULPHURIC ACID ABSORBENT

Waste Steam	49.7 psia	280.6° F
Upgraded Steam	89.7 psia	320° F
High Grade Steam	414.7 psia	448° F

Absorber Conditions

Concentration	55.9	57.3	58.7	60.1	62
°F	340	345	350	355	360
VP,* psia	49.3	49.3	49.3	49.3	49.3

Generator

Concentration	66.8	65.8	64.9	63.9	63
°F	430	425	420	415	410
VP,* psia	94.7	94.7	94.7	94.7	94.7

Note: Concentration is percent H_2SO_4 in total mixture

Mass Flows

Absorbed H_2O	1	1	1	1	1
Absorbent	3.425798	4.435694	6.144565	10.10629	39.06000
Circulating H_2O	2.702642	3.305482	4.323177	6.7095	23.94000

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* VP - vapor pressure.

Absorber Heat Balance, Btu

Steam hfg	924	924	924	924	924
Reheat	-60.77	-65.92	-71.07	-76.22	-81.37
Bond, vapour	74	84	91	98	112
Bond, dilution	84	60	41	27	7
Sensible	265.1125	313.6017	389.6339	564.6541	1864.464
Total, A	1286.342	1315.682	1374.564	1537.434	2826.094

Generator Heat Balance, Btu

Steam, hfg, B	892	892	892	892	892
Reheat, C	69.43	66.155	62.88	59.605	56.33
Bond, vapour	158	144	132	125	119
Sensible	354.7477	392.3129	457.0815	619.6027	1893.024
Condensate, D	184.2722	186.8085	192.9952	212.0260	370.0442
Total, Qin	1658.450	1681.276	1736.957	1908.234	3330.398
Qout, A+B+C+D	2432.045	2460.645	2522.439	2701.065	4144.468
COP, Qout/Qin	1.466457	1.463558	1.452218	1.415479	1.244436

Heat Exchanger Arithmetic Mean Temperature Differences

1 Xchg t1-t2	65	65	65	65	65
1 Xchg t1-t2	20	25	30	35	40
Regen t1-t2	18	23	28	33	38

Heat Exchanger Area Estimates

300 Btu/(h ft^2 °F) for liquid-liquid

500 Btu/(h ft^2 °F) for steam-liquid

Area 1	.0135955	.0160821	.0199812	.0289566	.0956135
Area 2	.170205	.1336107	.1094367	.0926457	.0801358

Area Regen	.1842722	.1461979	.1240683	.1156505	.1752841
Totals	.3680727	.2958908	.2534862	.2372529	.3510335

Heat Exchanger Area per lbm Conserved Steam/h

.7890826 .6383039 .5605403 .5710342 1.436094

kW*h/lbm Conserved Steam (Pump Efficiency .67)

.0003108 .0003811 .0005000 .0007768 .0027904

Chemical Heat Pump - Steam Quality Upgrading Using High Temperature Steam

The following statements describe the relationships between the entries in the first heat balance column. This is general for all columns

```
C8      = 55.9
C9      = 340
C10     = 49.3
C13     = 66.8
C14     = 430
C15     = 94.7
C18     = 1.0
C19     = C8/(100-C8-(100-C13)*C8/C13)
C20     = (100-C8)/(100-C8-(100-C13)*C8/C13)
C23     = 924
C24     = (281-C9)*1.03
C25     = 74
C26     = C33-C25
C27     = (C14-C9)*(.338*C19+1.05*(C20-1))
C28     = SUM(C23:C27)
C31     = 892
C32     = (C14-324)*.655
C33     = 158
C34     = (C14-C9)*(.338*C19+1.03*C20)
C35     = SUM(C31:C34)/800*100
C36     = SUM(C31:C35)
C38     = C31+C32+C28+C35
C40     = C38/C36
C43     = (C14+C9)/2-320
C44     = C9-320
C45     = 448-C14
C50     = C27/(300*C43)
C51     = (C28-C27)/(300*C44)
C52     = C36/(500*C45)
C53     = SUM(C50:C52)
C56     = 1/(C40-1)*C53
C59     = (C4-C3)*(C18+C19+C20)*1.09/1000000
```

APPENDIX 4

HEAT BALANCE - CAUSTIC SODA HEAT PUMP

APPENDIX 4

CHEMICAL HEAT PUMP - STEAM QUALITY UPGRADING USING HIGH TEMPERATURE STEAM - CAUSTIC SODA ABSORBENT

Waste Steam	49.7 psia	280.6 °F
Upgraded Steam	89.7 psia	320 °F
High Grade Steam	414.7 psia	448 °F

Absorber Conditions

Concentration	45	46.7	48.58	50.47	52.3
°F	345	350	355	360	365
VP,* psia	49.3	49.3	49.3	49.3	49.3

Generator Conditions

Concentration	61.33	59.06	57	55.04	53.2
°F	425	420	415	410	405
VP*, psia	94.7	94.7	94.7	94.7	94.7

Note - Concentrations are % NaOH in total mixture

Mass Flows

Absorbed H_2O	1	1	1	1	1
Absorbent	1.690049	2.231474	3.288670	6.078488	30.91511
Circulating H_2O	2.065615	2.546843	3.480926	5.965276	28.19600

---

* VP - vapor pressure.

Absorber Heat Balance, Btu

Steam hfg	924	924	924	924	924
Reheat	-65.92	-71.07	-76.22	-81.37	-86.52
Bond, vapour	190	197	204	213	225
Bond, dilution	80	59	44	27	10
Sensible	157.1137	191.7946	254.9585	412.6392	1760.534
Total, A	1285.194	1300.725	1350.738	1495.269	2833.014

Generator Heat Balance, Btu

Steam hfg, B	892	892	892	892	892
Reheat, C	66.155	62.88	59.605	56.33	53.055
Bond	270	256	248	240	235
Sensible	237.8087	236.4241	281.8155	409.9382	1779.977
Condensate, D	183.2455	180.9130	185.1776	199.7835	370.0041
Total, Qin	1649.209	1628.217	1666.598	1798.052	3330.036
Qout, A+B+C+D	2426.594	2436.518	2487.521	2643.383	4148.073
COP, Qout/Qin	1.471368	1.496433	1.492574	1.470137	1.245654

Heat Exchanger Arithmetic Mean Temperature Differences

1 Xchg t1-t2	65	65	65	65	65
1 Xchg t1-t2	25	30	35	40	45
Regen t1-t2	23	28	33	38	43

Heat Exchanger Area Estimates

300 Btu/(h ft^2 °F) for liquid-liquid

500 Btu/(h ft^2 °F) for steam-liquid

Area 1	.0080571	.0098356	.0130748	.0211610	.0902838
Area 2	.1504107	.1232144	.10436	.0902192	.0794430
Area Regen	.1434095	.1163012	.1010059	.0946343	.1548854
Totals	.3018773	.2493513	.2184407	.2060144	.3246122

Heat Exchanger Area per lbm Conserved Steam/h

.6404275 .5022860 .4434678 .4382007 1.321420

kW*h/lbm Conserved Steam (Pump Efficiency .67)

.0002073 .0002519 .0003388 .0005687 .0026208

Chemical Heat Pump - Steam Quality
Upgrading Using High Quality Steam

The following statements describe the relationships between the entries in the first heat balance column. This is general for all columns:

```
C8      = 45
C9      = 345
C10     = 49.3
C13     = 61.33
C14     = 425
C15     = 94.7
C18     = 1.0
C19     = C8/(100-C8-(100-C13)*C8/C13)
C20     = (100-C8)/(100-C8-(100-C13)*C8/C13)
C23     = 924
C24     = (281-C9)*1.03
C25     = 190
C26     = C33-C25
C27     = (C14-C9)*(.50*C19+1.05*(C20-1))
C28     = SUM(C23:C27)
C31     = 892
C32     = (C14-324)*.655
C33     = 270
C34     = (C14-C9)*(.50*C19+1.03*C20)
C35     = SUM(C31:C34)/800*100
C36     = SUM(C31:C35)
C38     = C31+C32+C28+C35
C40     = C38/C36
C43     = (C14+C9)/2-320
C44     = C9-320
C45     = 448-C14
C50     = C27/(300*C43)
C51     = (C28-C27)/(300*C44)
C52     = C36/(500*C45)
C53     = SUM(C50:C52)
C56     = 1/(C40-1)*C53
C59     = (C4-C3)*(C18+C19+C20)*1.09/1000000
```

APPENDIX 5

CHEMICAL HEAT PUMP FOR HIGH EFFICIENCY DRYING

APPENDIX 5

Mass and energy balance at paper drying system components.

(a) Balance at Drying Hood

(1) Water content (difference between moisture content of paper entering and leaving hood). Balance for 1 lbm.

(2) Steam to drying rolls--assume 50 psia saturated.

(3) Condensate from rolls.

(5) Dehydrated air entering hood.

(b) Balance at Absorption Column

(1) Weak absorbent leaving.
(2) Strong absorbent entering.
(3) Air from hood--see above.

(c) Balance at Regenerator

(1) Superheated steam leaving to condenser.
(2) Absorbent--see above.
(3) Condensate from rolls--See a(3).
(4) Atmospheric pressure waste steam.

Absorber conditions

120°C (248°F), 90 g N_aOH/100 g H_2O
(47.36 percent N_aOH)
330 mm (6.39 psia) vapor pressure

Generator conditions

80°C (176°F), 100 g N_aOH/100 g H_2O (50 percent N_aOH)

Assume water is available at 70°F to condenser vapor from the generator

Mass Flows

Absorbed H_2O	1.0 lbm
Absorbent N_aOH	9.0 lbm
Circulating H_2O	9.0 lbm

Air entering absorber

200°F, 60 percent RH
SVP of water at 200°F is 11.5 psia
therefore VP of water is .6 x 11.5 = 6.9 psia
Specific volume of water, V_g = 33.71 ft^3/lb at 200°F, 11.5 psia
therefore at 60 percent RH, volume of water is
33.71 percent/.6 = 56.18 ft^3/lbm water
Volume of air 200°F, pressure (14.7 - 6.38) =

$$\frac{359}{28.96} \times \frac{(460 + 248)}{492} \times \frac{14.7}{14.7 - 6.38} = 31.52 \text{ ft}^3\text{/lbm air}$$

therefore mass of air is

$$\frac{56.18}{31.33} = 1.793 \text{ lbm/lbm water vapor entering}$$

Air leaving absorber

248°F, 6.38 psia VP of water)
SVP of water at 248°F is 28.75)

therefore $\frac{6.38}{28.75}$ = 22 percent RH

Specific volume of water, Vg =

$14.19 \times \frac{28.75}{6.38} = 63.944$ ft^3/lbm water

Volume of air, 248°F, pressure (14.7 - 6.38) =

$\frac{359}{28.96} \times \frac{(460 + 248)}{(492)} \times \frac{14.7}{14.7-6.38} = 31.52$ ft^3/lbm air

therefore mass of air is

$\frac{63.944}{31.52} = 2.0287$ lbm air/lbm water vapor leaving

Mass of air entering equals mass of air leaving, hence for 1.793 lbm air entering (with 1 lbm water vapor)

$\frac{1.793}{2.0287} = .8837$ lbm vapor leaves

therefore 2 - .8837 = .1162 lbm vapor is absorbed

therefore $\frac{1.793}{.1162}$ = 15.42 lbm air circulates per lbm air absorbed into N_aOH absorbent.

Mass/Energy Balance in Drying Hood

1 lb_m water removed from paper at 200°F, h_{fg} = -978 Btu

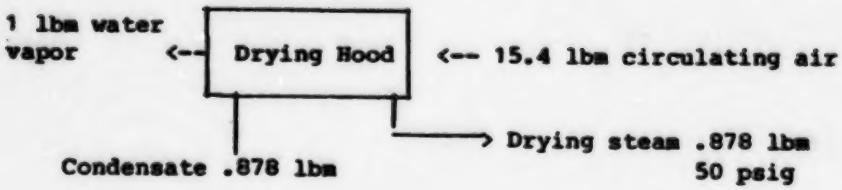
Circulating air, 15.42 lbm, cooling 248 to 200

.24 x 15.42 48 = 177 Btu

Steam condensing in rolls, h_{fg} = 912 Btu

therefore mass of steam to rolls is

(978 - 177)/912 = .878lbm/lbm water removed

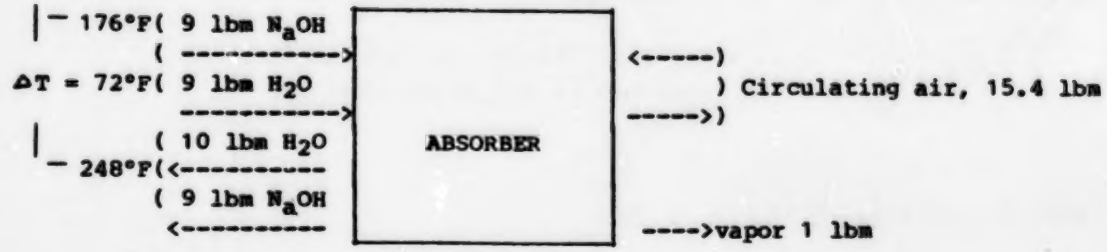


Mass/Energy Balance in Absorber

		Btu
Heat gains	condensation of 1 lbm vapor	978
	bond energy (Appendix 2)	210
	dilution energy (bond energy)	10
		1,198

		Btu
Heat losses	circulating air (see above)	177
	sensible heat, absorbent .72 x (9 x 1 + 9 x .5)	972
	Reheat 1 lbm condensate	36
		1,185

Good match--some excess heat for losses from hood.



Mass/Energy Balance in Generator

Sensible heat gain, absorbent 72(10 x 1 + 9 x 0.5) = 1,044 Btu

	Btu
Bond energy	-200
Evaporation (condensing at 70°F)	-1,054
Superheat (176 - 70) x .46	-49
	-1,303

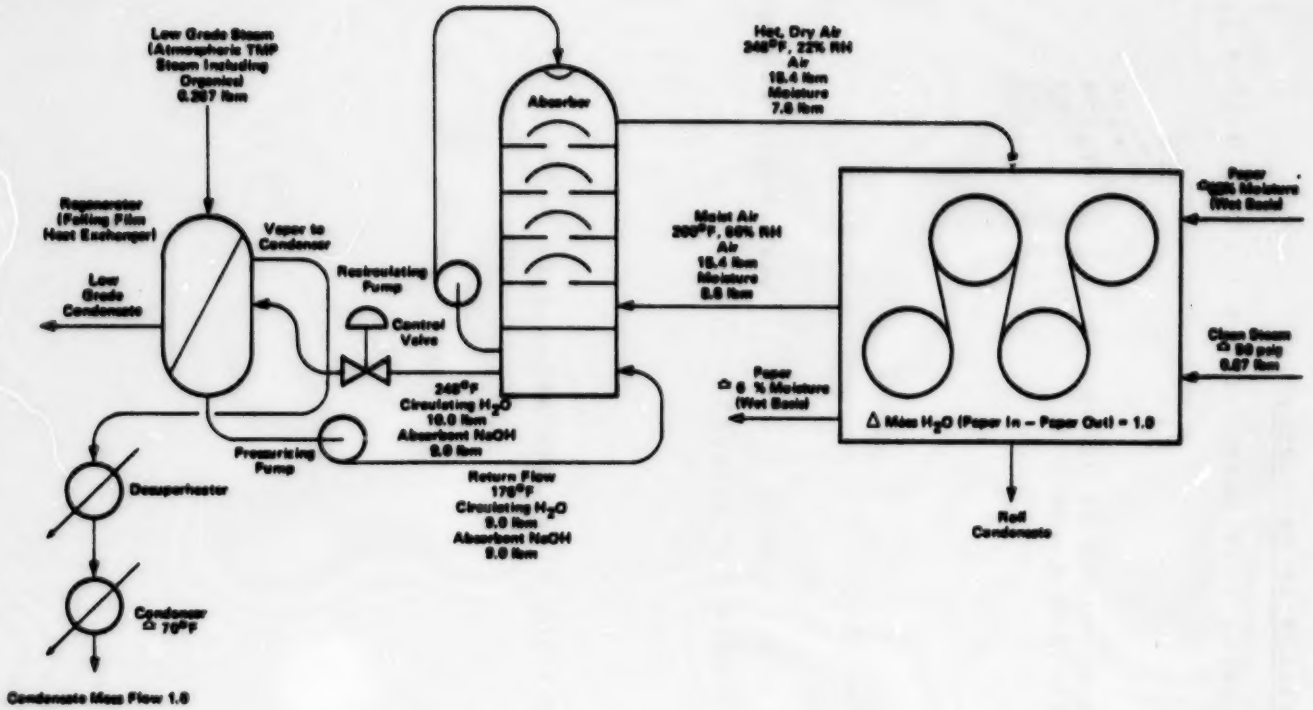
Deficit

1,303 - 1,044 = 259 Btu

Deficit to be made up with low grade heat e.g., atmospheric pressure steam from TMP process.

h_{fg} = 970

$\frac{258}{970}$ = .267 lbm steam/lbm water from paper



NOTE: Mass Flow in lbm

Figure A5-1

CHEMICAL HEAT PUMP FOR
HIGH EFFICIENCY PAPER DRYING

APPENDIX 6

ONTARIO PAPER CO.'S LETTER OF FEBRUARY 17, 1984

Ontario Paper Company

February 17, 1984

Acres Consulting Services Ltd.
P.O. Box 1001
5259 Dorchester
Niagara Falls, Ontario
L2E 6W1

Attention: Mr. Oscar Gaube

Dear Oscar:

It was a pleasure to meet with you and your associates to discuss the potential of heat recovery by chemical means and its possible application to pulp and paper mills.

At the present time, we are actively studying the possibility of recovering clean steam from the waste heat leaving our refiners. This waste heat source may be of interest to you as a possible application of the chemical heat recovery system. It is estimated that we could recover, by conventional means, the equivalent of 90,000 lbs. of clean steam at 35 psig pressure. To utilize this quantity of steam in our paper machine dryers, it must be pressurized to 75 psig.

If the proposed chemical heat recovery system could deliver approximately the same quantity of clean steam at 75 psig, then it would certainly enjoy an advantage over the other heat recovery system studied to date, and would be of interest to us and possibly other mills.

You indicated that sulphuric acid or possibly caustic soda might be the chemical selected as heat recovery media. The mill consumes large quantities of both chemicals. Caustic soda may be preferable, since it is expected the corrosion problems will not be as severe as those associated with the use of sulphuric acid.

Before a heat recovery system based on the use of strong chemicals becomes a commercial reality, a number of environmental, safety, and operating problems will require resolution. If we can

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A division of QNS Paper Company Limited

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be of further assistance in providing any information, please advise; we will be happy to co-operate.

Please do not construe anything in this letter as a commitment by Ontario Paper Company. At this time, we are only interested in obtaining additional information on the system and evaluating its heat recovery potential.

Yours very truly,

N. F. Pridham, P. Eng.
Senior Corporate Engineer

NFP/jl

c.c. Mr. B. Baril